Thermoforming Process

Thermoforming normally consists of heating a thermoplastic sheet until the forming temperature *(Basically the raw material is transformed by heating into a viscous - flexible phase)* is reached and forming the hot and flexible material against the contours of a mold by mechanical means (e.g., tools, plugs, solid molds, etc.) or pneumatic means (e.g., differentials in air pressure created by pulling a vacuum or using the pressures of compressed air). The formed part cools in the tooling and is subsequently demolded. Due to cooling down, the orientations of the molecule chains keep their stretched positions. Re - heating results in a recovery to the original sheet state.

RAW MATERIALS

1. PC, PMMA, PA, POM, and ABS as well as fiber - reinforced composites and self - reinforced materials are semifinished products for technical applications. For the automobile industry, often thermoplastic elastomers and thermoplastic polyolefins are used.
2. PET, PS, PP, PVC, and PE are semifinished products for packaging applications.

THERMOFORMING METHODS

The forming technologies are differentiated into the following subgroups:

- Positive
- Negative
    a. Compressed air
    b. Vacuum
    c. Plug assisted
- Lamination

To some extent these methods can also be combined.

POSITIVE FORMING

In the positive forming method, the heated semifinished product (sheet) is drawn over the forming mold. The definition is on the inside of the finished part. During the forming process the inside has contact with the forming mold and takes over its shape.

In a first step, the thermoplastic semifinished product is brought to its forming temperature. In order to receive a uniform wall thickness distribution, the material is pre - streched by means of pre - blowing. After this, the mold closes, and vacuum is applied to bring the material to its final shape. Demolding takes place after the plastic has cooled.

NEGATIVE FORMING

A common application of negative forming is in the production of cups. After the heated film has been positioned in the forming station, the mold closes. As the plug assist pulls down, the trapped air in the cavity is released by means of venting holes. Then the forming air is applied and the part receives its final shape. Demolding takes place after the plastic has cooled down.

ADVANTAGES AND DISADVANTAGES OF THERMOFORMING

Thermoforming is mostly in concurrence with injection molding. The advantages and disadvantages listed below principally refer to a comparison with injection molding.

The manufacturing of technical articles by forming has the following advantages:

- Heavy parts can be produced (up to 125 kg)
- Large parts can be manufactured (up to 4 m^2)
- Flexible wall thickness (0.05 – 16 mm)
- Cost - effectiveness for small batches (tooling costs)
- Low costs for modifications and for color change
- Homogeneous multilayer applications are possible

The manufacturing of packaging parts by forming has the following advantages:

- Shorter cycle times
- High output
- Processing of printed semifinished product is possible
- Processing of multilayered semifinished product is possible

The disadvantages of thermoforming are the following:

- Less scope for design (undercuts)
- No uniform distribution of wall thickness
- Temperature control is difficult
- For a given semifinished product, the manufacturer has no influence over the formulation of the film, if dealing with purchased film.

THERMOFORMING PROCESSES

Vacuum Forming into a Female Mold

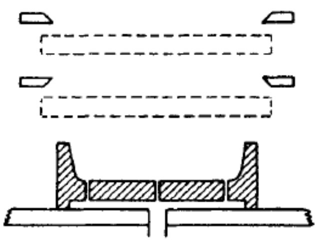
To vacuum form a thermoplastic sheet into a female mold without prestretching, the ratio of depth to minor dimension of a given section should not be greater than **1** : **1,** and no sharp inside radii are required.

The process

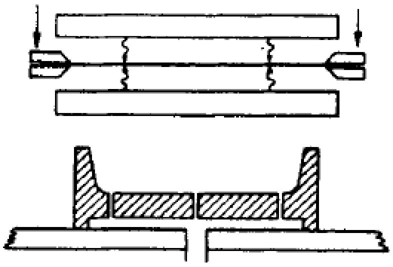
The sheet stock is locked in a frame around its periphery only and is heated to a predetermined temperature, and then it is brought into contact with the edge of the mold. This contact should create a seal so that it is possible to remove the air between the hot plastic and the mold, allowing atmospheric pressure to force the hot plastic against the mold. Most thermoplastics sheets (with the exception of cast acrylic) can be easily formed with vacuum.

The reasons for using a female mold are: greater details can be achieved on the outer surface of the part; multiple cavities can be placed closer together; and this type is easier to work with when close tolerances are needed on the outside of the part. However female molds are more expensive to make than male molds.

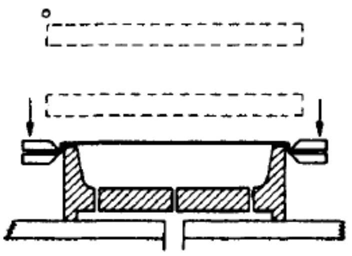
THERMOPLASTIC SHEETS



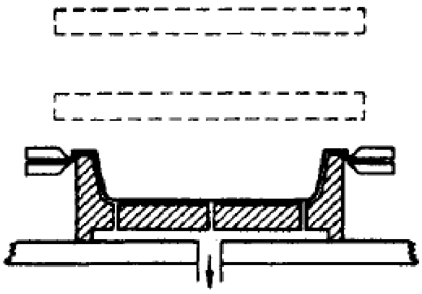
Female mold on platen—frames open—heaters idle.



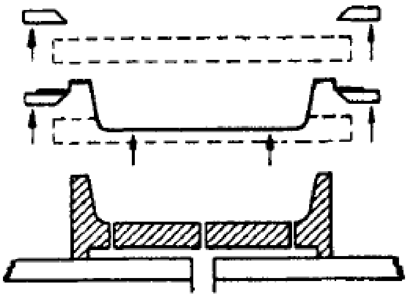
Stock in place—frames closed—heaters active.



Heaters idle—frames lowered, drawing stock into contact with mold.



Vacuum applied—stock cooling.



Cycle completed—equipment idle.

Fig. 13-1. Vacuum forming.

Pressure Forming into Female Cavity

Instead of relying on atmospheric pressure against a vacuum, positive air pressure *(formed by compressed air at up to 500 psi)* is applied against the top of the sheet to force it into a female mold, and, at the same time, full vacuum also is applied. As contrasted to vacuum forming, pressure forming offers a faster production cycle (the sheet can be formed at a slightly lower sheet temperature), greater part definition, and greater dimensional control.

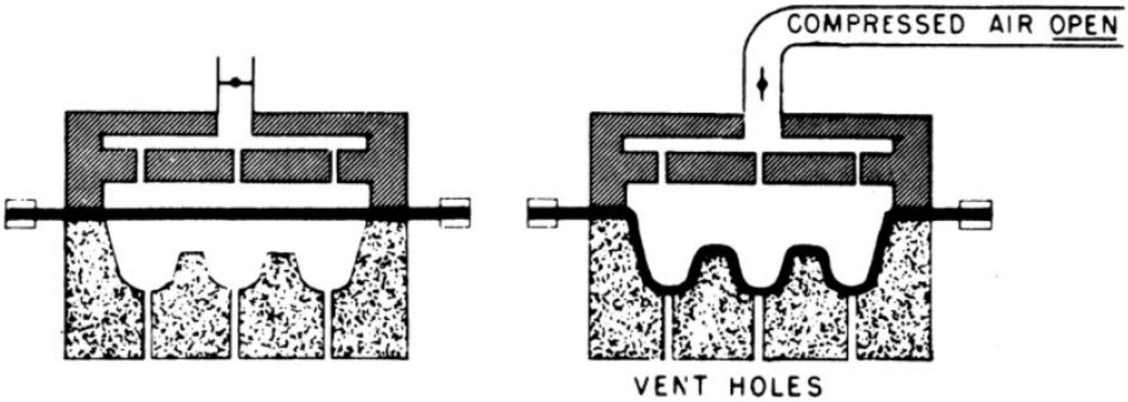
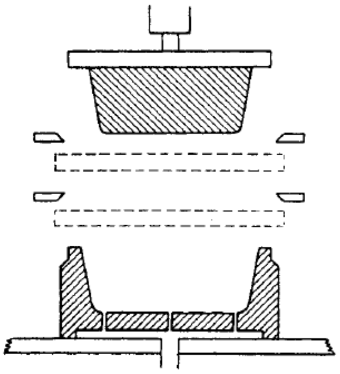


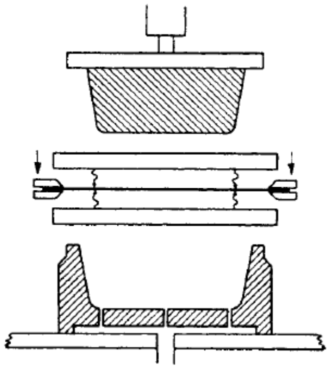
Fig. 13-2. Pressure forming into female cavity. Heated sheet is clamped over cavity, and compressed air pressure forces the sheet into the mold. (*Courtesy Dow*)

Plug-Assist Forming

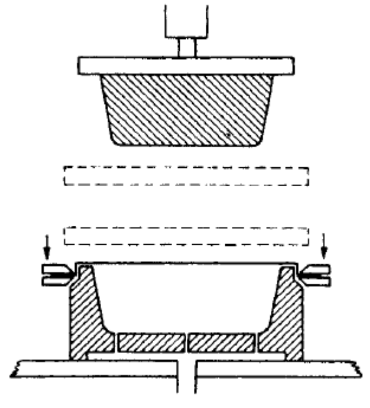
Straight cavity forming is not well adapted to forming a cup or box shape products. The sheet, drawn down by vacuum, touches first along the side walls and then at the center of the bottom of the box-shaped mold and starts to cool there, with its position and its thickness becoming fixed. As the sheet continues to fill out the mold, solidification continues in such a way as to use up most of the stock before it reaches the periphery of the base; hence this part of the article will be relatively thin and weak. This characteristic is undesirable in a cup shape, and usually unacceptable in a box shape, in which the thinness will be most marked at the comers of the base. To promote uniformity of distribution in such shapes, designers use the plug assist type of mechanical helper that carries extra stock toward an area that otherwise would be too thin. Usually the plug is made of metal, and heated to a temperature slightly below that of the hot plastic, so as not to cool the stock before it can reach its final shape. Instead of metal, a smooth-grained hard wood can also be used, or a felt-covered phenolic or epoxy; these materials are poor conductors of heat and hence do not withdraw much heat from the sheet stock. Synthetic foam has been very popular for this application. The plug-assist technique is shown below. Plug-assist techniques are adaptable to both vacuum forming and pressure forming techniques. The system shown below is known as plug-assist vacuum forming in that a vacuum is drawn after the plug has reached its closed position to complete formation of the sheet. In plug-assist pressure forming, the process differs in that after the plug enters the sheet, a partial vacuum is applied. Where the plug bottoms out, a full vacuum is drawn, and compressed air is applied to the opposite side. As opposed to plug-assist vacuum forming, pressure forming offers more uniform material distribution over the entire formed part (see Fig. 13-5).



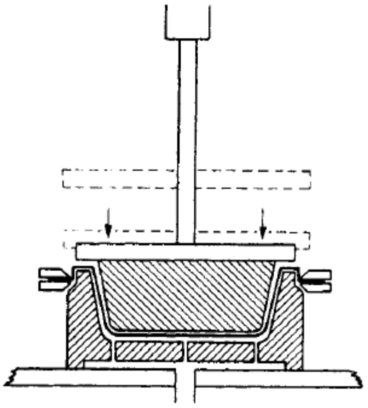
Female mold and plug assist mounted—
frames open—heaters idle.



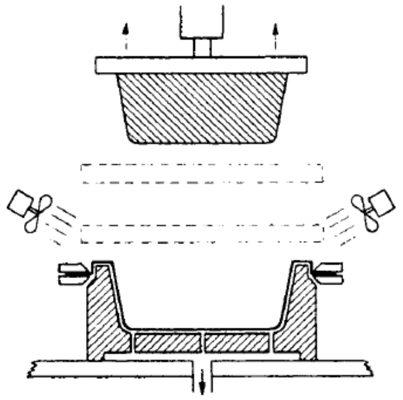
Stock in place—frames closed—heaters active.



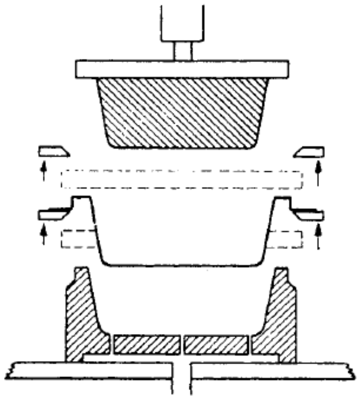
Heaters idle—frames lowered,drawing stock
into contact with mold.



Plug assist lowered—prestretching the stock.



Vacuum applied—plug assist retracted—fans operating.



Cycle completed—equipment idle.

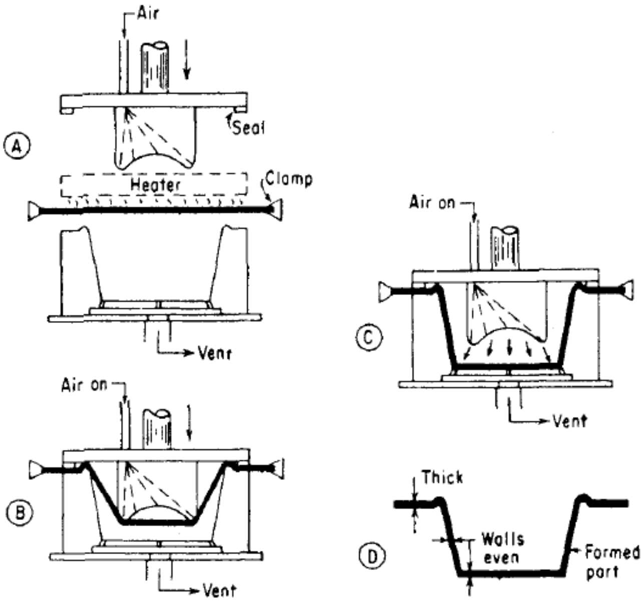


Fig. 13-5. Plug-assist pressure forming. (*Courtesy McGraw-Hill*)

Matched Mold Forming

This mechanical techniques that use neither air pressure nor vacuum is matched mold forming (below Fig.). In this operation, the plastic sheet is locked into the clamping frame and heated to the proper forming temperature. **A** male mold is positioned on either the top or the bottom platen with a matched female mold mounted on the other one. The mold then is closed, forcing the plastic to the contours of both molds. The clearance between the male and female molds determines the wall thickness. Trapped air is allowed to escape through both mold faces. Molds are held in place until the plastic cools and cures. Matched mold forming offers excellent reproduction of mold detail and dimensional accuracy. Internal cooling of the mold is desirable in this technique.

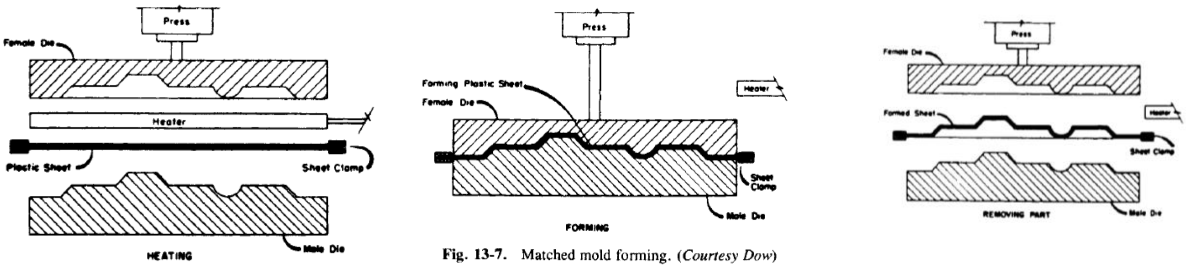


Fig. 13-7. Matched mold forming. (*Courtesy Dow*)

Dual Sheet Forming

A number of techniques have been made available for the production of hollow products by thermoforming. Typical is the concept of dual sheet thermoforming (also known as twin-sheet forming). It operates as follows: Two rolls of plastic sheet are automatically fed, one above the other, with a predetermined space in between, through the heating stations and into the ‘forming station. Here a blow pin enters **at** the central point of the hollow object (i.e., in between the two sheets), and the upper and lower halves of the tool close onto the sheets and pinch off around the entire perimeter. High pressure air then is introduced between the two sheets from the blow pin, and a vacuum is applied to each of the two mold halves. The hollow object then indexes forward, and the next two segments of sheet move into place for forming. In one variation of the process, urethane foam instead of air pressure is introduced between the two sheets. The urethane bonds to the two skins, forming a rugged sandwich construction. This technique is applicable to the manufacture of urethane foam-filled boat hulls. Another technique for making hollow products is known as clam-sheel forming. This is a sheet-fed technique involving the use of a rotary-type machine. The individual sheets are placed in separate clamp frames, and then indexed through the heating station and into the forming station. Here, a vacuum is applied to both halves of the mold to draw the upper sheet into the upper mold half and the lower sheet into the lower mold half. Still another method, known as twin-shell forming, involves the use of a series of continuously moving molds (traveling on belts) that clamp onto the sheets (feeding off rolls) and travel with them as the vacuum is pulled and the sheet halves are formed. (See Fig. **13-16.)**

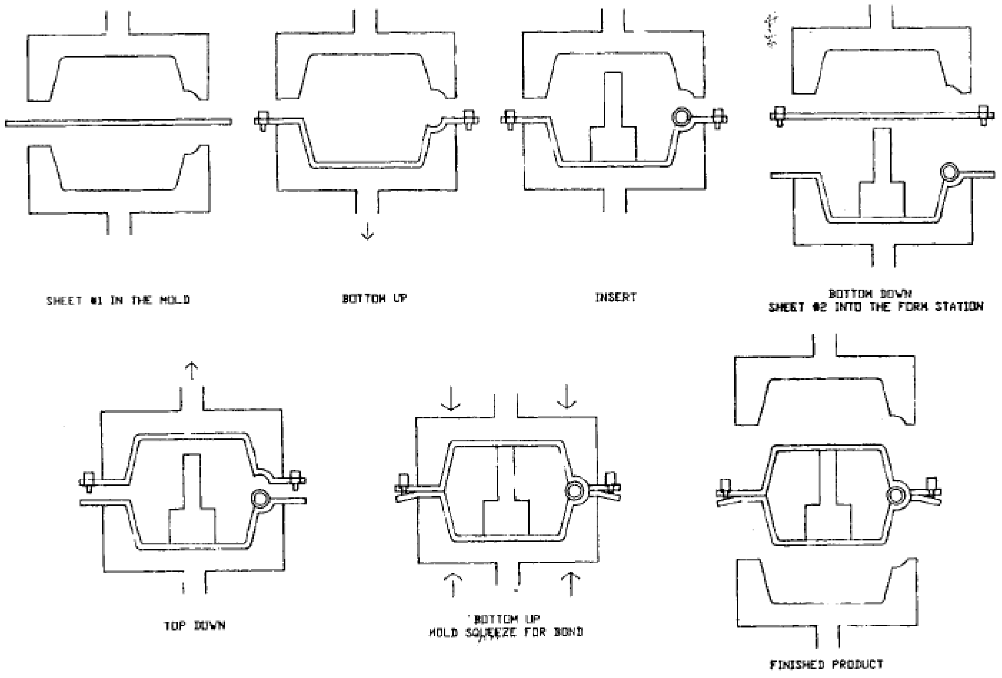


Fig. 13-16. Dual-sheet forming. (*Courtesy CAM/Central Automated Machinery, Inc.*)

Thermoforming Machinery

There are two general thermoforming categories.

1. Typically, heavy-gage sheet is handled as discrete cut sections and the forming equipment are called cut-sheet thermoformers.
2. Thin-gage sheet is handled in continuous rolls and the forming equipment is usually called roll-fed thermoformers.

The equipment in both categories includes:

1. Some form of sheet handling device,
2. A way of moving the sheet from one station to another,
3. A means of controlling the various elements that allow the sheet to be heated, formed and moved from station to station,
4. A sheet heating oven,
5. A vacuum system,
6. A forming press, and
7. A formed part removal region.

In addition, the equipment may include:

1. Some form of prestretching such as:
    a. preblowing or
    b. plug assist,
2. A pressure system,
3. A trimming press, and
4. Some form of trim removal.

Machines often are classified according to the number of operations they perform.

Single-Stage, Sheet-Fed Machines

A single-stage machine can perform only one operation at a time, and its total cycle will be the sum of the times required for loading, heating, forming, cooling, and unloading. In a typical operation, the sheet is clamped in a frame, and the frame is moved between the heaters (or under a single heater) and back to the forming station for thermoforming.

Multiple-Stage, Sheet-Fed Machines

A two-stage machine can perform two operations simultaneously. It usually consists of two forming stations and a bank of heaters that move from one station to the other. Machines with three stages or more usually are built on a horizontal circular frame and are called rotaries. The rotary thermoformer operates like a merry-go-round, indexing through the various stations. **A** three-stage **ro**tary machine would have a loading and unloading station, a heating station, and a forming station, where cooling also takes place, and would index 90° after each operation. Because there is always a sheet in each of the stations, it provides considerably higher output than a single-station machine.

Four stage rotary can incorporate various station configurations (i.e., load, unload, **preheat, heat, form or load, heat, form and unload.**

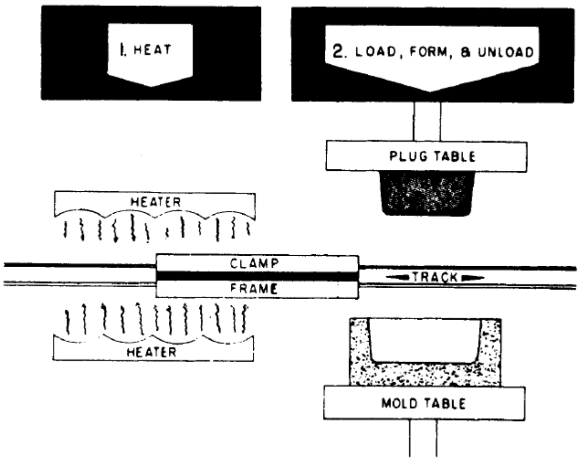


Fig. 13-19. Single-stage forming unit. (*Courtesy Dow*)

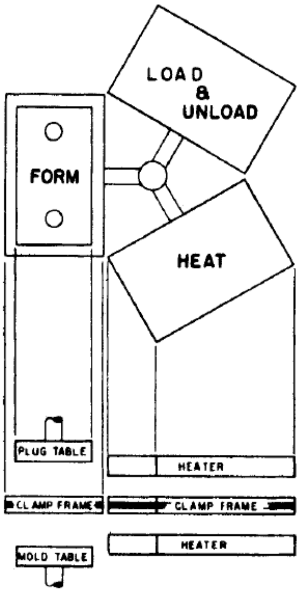


Fig. 13-20. Three-stage rotary unit. (*Courtesy Dow*)

In-Line, Sheet-Fed Machines

Here, the sheet follows the same pattern as a caterpillar track. The sheet is clamped in a frame that travels into the heating station, then indexes through the forming station and on to the unloading station, where the part is removed by the operator. This type of machine has a total of five clamp frames in use at all times.

Continuous Roll-Fed Machines

In the early days of thermoforming, continuous forming machines that fed off a roll of plastic or directly from an extruder used either a rotating cylinder as the mold (drum former) or conventional molds that traveled horizontally at the same speed as the sheet (the upper and lower platens moved with the sheet but had a reciprocating motion so that they could index to the next unformed section of sheet, once the forming cycle was complete). The workhorse of the industry today, however, is the intermittently fed continuous forming machine (used for thin wall containers, disposable cups, lids, etc.). This machine is fed either from a roll or directly from an extruder. As opposed to the systems described above, however, the sheet is indexed through the machine intermittently. It is considerably faster than those techniques where the sheet is continuously moving through the machine, and the molds have to move back and forth. In a typical operation, the sheet feeds off a roll at the rear of the thermoformer into a set of conveying chains that indexes the sheet intermittently forward through heating, forming, and trimming. Once the roll of material is threaded through the system, it functions completely automatically and can cycle as fast as two seconds.

Heating of Thin-Gage Sheet

There are three ways of heating sheet:

1. **Conduction**, where the sheet is placed in direct contact with the heating medium, such as a hot plate,
2. **Convection**, where the sheet is heated with hot air, and
3. **Radiation**, where infrared heat from metal wires, ceramic plates, or gas-fired combustion is the primary means of heating the sheet.

Thin-gage, roll-fed sheet is usually heated by passing the sheet between banks of infrared radiant heaters. Combinations of radiation and convection heating are used as well. Most plastics formed such as PS, PVC and ABS, are formed at relatively low temperatures such as 120°C to 230°C.

Heating Heavy-Gage Sheet

Intense energy input from radiant heaters is unwarranted and is potentially a problem for heavy-gage sheet. Conduction of the energy from the surface of the sheet to its interior controls the heating time. As a result, heavy-gage sheet is frequently heated with forced convection hot air or reradiated energy from fine mesh metal screens or hot plates. Heater types and temperatures are selected on the basis of optimizing the amount of energy transferred to the sheet per unit time.

Hot Strength

All thermoplastic sheet materials can be stretched when hot, but this property varies greatly with different materials, and under different conditions, and it is measurable. It is intimately related to temperature and to speed of elongation, and, in many of the methods described earlier, it is of critical importance. Because of its dependence on the correct temperature, methods of heating, methods of stretching or forming, choice of material for molds, and related methods of cooling on the mold, hot strength is referred to frequently. Some commercial sheet stocks can be stretched as much as 500 or 600% over their original area; others stretch as little as **15** to 10%. Naturally this characteristic has a great influence on what shapes can be produced and the quality of what is produced. Some materials at forming temperatures become almost puttylike and respond to a minimum of pressure, either pneumatic or mechanical, in such a way as to pick **up** every detail of the mold. Others exhibit strong resistance, and thus require heavier equipment and tools. The limited differential of pressure available in vacuum methods may not suffice to provide small details in some formed articles. In such cases, compressed air can be added. This property is somewhat related to the ability to be stretched while hot, but does not run parallel to it. The hot strength of thermoplastics vanes dramatically with temperature changes, but very little with gauge variations.

Temperature Range for Forming

Amorphous thermoplastics (ABS, acrylic, styrene, polycarbonate, and vinyl, for example) do not have melting points. Their softening with increase of temperature is gradual, and each material has its own range of specific processing temperatures. Selection of the forming temperature comes by knowing the degradation temperature and then determining the highest temperature under that where the sheet has enough "hot strength" to handle and still form properly.

Crystalline thermoplastics, such as polyethylene, polypropylene, and nylon, have sharp melting points. Unfortunately, most of the forming temperatures are the same as the melting temperatures. Polypropylene should be heated to 330°F for the proper thermoforming temperature; however, regular grades ***melt*** at 330°F. Special grades and modifiers have been developed recently to give good hot strength at these temperatures.

Thermoforming Processing Temperatures

1. ***Mold and Set Temperature.*** The set temperature is the temperature at which the thermoplastic sheet hardens and can be safely taken from the mold. This is generally defined as the heat distortion temperature at 66 psi (455 kPa). The closer the mold temperature is to the set temperature without exceeding it, the less one will encounter internal stress problems in the part. For a more rapid cycle time, if postshrinkage is encountered, post-cooling fixtures can be used so that parts may be pulled early.

2. ***Lower Processing Limit.*** This column shows the lowest possible temperature for the sheet before it is completely formed. Material formed at or below this limit will have severely increased internal stress that later can cause warpage, lower impact strength, and other poorer physical properties-another reason for rapid vacuum or forming pressure. The least amount of internal stress is obtained by a hot mold, hot sheet, and very rapid vacuum and/or compressed air.

3. ***Orienting Temperatures.*** Biaxially orienting the molecular structure of thermoplastic sheet approximately 275 to 300% at these temperatures and then cooling greatly enhances properties, such as impact and tensile strength. Careful matching of heating, rate of stretch, mechanical stresses, and so on, is required to achieve maximum results. In thermoforming oriented material, good clamping of the sheet must be used. The sheet is heated as usual to its proper forming temperature and thermoformed. The hot forming temperatures do not realign the molecular structure; therefore, the better properties of the oriented sheet are camed into the finished part.

4. ***Normal Forming Temperature.*** This is the temperature that the sheet should reach for proper forming conditions under normal circumstances. ***The core (interior) of the sheet must be at this temperature!*** The normal forming temperature is determined by heating the sheet to the highest temperature at which it still has enough hot strength or elasticity to be handled, yet below the degrading temperature.

5. ***Upper Limit.*** This is the temperature at which the thermoplastic sheet begins to degrade or decompose. It is crucial to ensure that the sheet temperature stays below this value. When radiant heat is used, the sheet surface temperature should be carefully monitored to avoid degradation while waiting for the “core” of the material to reach forming temperature. These limits can be exceeded, if for a short time only, with minimum impairment of the sheet properties.

TRIMMING

Unlike injection molding, 90% of thermoformed parts undergo some type of trimming operation. Because a sheet of material must be clamped on its edges to allow stretching of the sheet into a shape, edge trim must be removed. In the forming of multiple parts (e.g., cups or plates) a space is allowed between molds for clamping, leaving a skeleton-like web after the parts are trimmed or punched out. The reduction of edge trim or space trim could greatly affect the overall manufacturing costs, as an average trim scrap factor in thermoforming is **10** to 20%. High-speed roll-fed thermoformers usually are run in-line with a high-speed trim press. Synchronized to the output of the thermoformer, this equipment can be microprocessor controlled, and can incorporate parts ejection for deep draw parts, packing tables, stackers, and counters, or utilize downstream equipment such as packaging equipment and/or lip rollers.

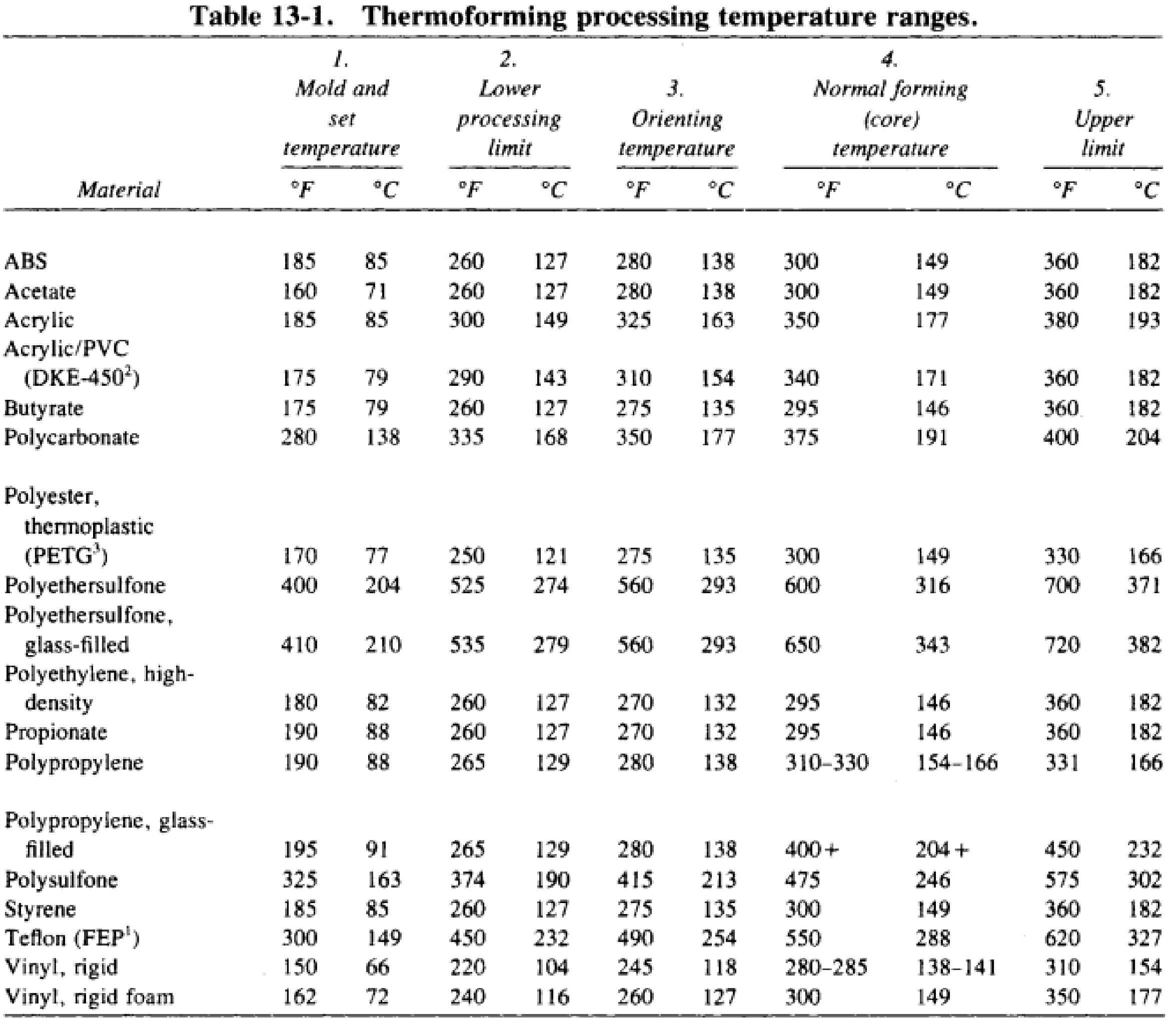


Table 13-1. Thermoforming processing temperature ranges.

	1. Mold and set temperature		*2. Lower processing limit*		*3. Orienting temperature*		*4. Normal forming (core) temperature*		*5. Upper limit*	
Material	*°F*	*°C*	*°F*	*°C*	*°F*	*°C*	*°F*	*°C*	*°F*	*°C*
ABS	185	85	260	127	280	138	300	149	360	182
Acetate	160	71	260	127	280	138	300	149	360	182
Acrylic	185	85	300	149	325	163	350	177	380	193
Acrylic/PVC (DKE-450^2)	175	79	290	143	310	154	340	171	360	182
Butyrate	175	79	260	127	275	135	295	146	360	182
Polycarbonate	280	138	335	168	350	177	375	191	400	204
Polyester, thermoplastic (PETG^3)	170	77	250	121	275	135	300	149	330	166
Polyethersulfone	400	204	525	274	560	293	600	316	700	371
Polyethersulfone, glass-filled	410	210	535	279	560	293	650	343	720	382
Polyethylene, high-density	180	82	260	127	270	132	295	146	360	182
Propionate	190	88	260	127	270	132	295	146	360	182
Polypropylene	190	88	265	129	280	138	310–330	154–166	331	166
Polypropylene, glass-filled	195	91	265	129	280	138	400+	204+	450	232
Polysulfone	325	163	374	190	415	213	475	246	575	302
Styrene	185	85	260	127	275	135	300	149	360	182
Teflon (FEP^1)	300	149	450	232	490	254	550	288	620	327
Vinyl, rigid	150	66	220	104	245	118	280–285	138–141	310	154
Vinyl, rigid foam	162	72	240	116	260	127	300	149	350	177

Scrap granulators are often placed under the press. Trim tooling incorporates punches and dies. The web of formed parts is threaded into the trim press, either manually or automatically. From that point on, the press trims and ejects parts as the machine forms and ejects webs of parts. Trim-in-place thermoforming machines are becoming more popular, where trimming takes place in the form station. This is especially desired in forming exotic, multilayer, bamer, or polypropylene materials. Steel-rule die trim stations are incorporated into many thermoforming machines to provide forming and trimming in one unit. Although not so fast and accurate as an off-line trim press, this is desirable for many nonfood items such as horticultural trays, box inserts, and blister packaging. Trimming of cut-sheet parts usually is done off-line. New methods include robotics, lasers, and high-pressure water-jet systems. Other methods are routing and drilling, sawing, hotwire, and deburring. New equipment developments are providing automated parts handling to an automated trimming station. The method most often used in trimming (and punching) large, high-production, relatively flat articles, such as refrigerator door liners, requires handling by the operator, who places the untrimmed piece into a press, activates it through the cycle, and then removes the article and the trim scrap.

Tools for trimming are described below:

Shear Dies. These are the obvious tools for trimming large production runs of large articles if they are trimmed on a single level. These dies are built as if they were intended to trim metal articles, are mounted on die shoes, and are operated in metal-working presses. Some plastics require quite close tolerances between die members. The power required is about one-third of that required to shear mild steel of equal thickness.

Steel-Rule Dies. These are made of strip steel about & inch thick and 1 inch wide, with one sharpened edge. The strips are formed to the shape of the trim line, and held to that shape by birch die stock. They are practical in small to medium runs, and for most thermoplastics in thin to medium thicknesses. Some of the more brittle plastics can be cut by this process only when warm, before they have cooled after forming, **or** by post-heating the part or the die.

Walker Dies. These dies are known also as envelope dies or high dies. They are a heavy duty version of the steel-rule dies, in that they are forged to about & inch thickness, and they are available up to 4 inches high, and thus may provide clearance for projections in the article to be trimmed.

Planetary Dies. These dies provide for side motion and they progressively shear vertical flanges on the respective sides of an article. They require special machines.

Machinery for Trimming. It is obvious that tools similar or identical to those used in metal work should be used on the same type of equipment regardless of material. Therefore, trimming of plastics often is done on punch presses, press brakes, and other toggle-action machines. Hydraulic presses are entirely satisfactory, and frequently are moved into the forming area so that the operator who runs the forming machine is able to trim articles jut formed, within the duration of the next forming cycle. The special contour dies such as the steel rule and envelope types are used on clicker and dinker machines such as those used in the leather industry, on continuous or clutch-type toggle presses, and on hydraulic presses. Saws are used for many operations where a vertical flange is to be trimmed. **A** radial-arm type is readily adjustable and direct drive yields appropriate blade speed. If articles are registered from the table area, clearance beneath the saw blade can be provided. Bandsaws in both vertical and horizontal positions are efficient in trimming hat-shaped parts. Wood shaper machines also are used, but are not so adaptable.

Trimming in the Mold

This innovation makes it possible to trim formed articles at the forming station. One method of trimming-in-place incorporates a knife edge around the periphery of the forming die and a movable heated ring directly over the die. After the object is formed in the conventional manner, but before it is cool, the heated ring drops down and presses against the knife edge in the mold and pinches the part from the web. The process may also work in reverse by placing a heated knife edge on the upper platen and bringing it in contact with the sheet against a flat mold surface. The problem with this method is that plastic may build up on the trimmer and reduce its effectiveness. Another method uses shearing dies, which either punch a section of sheet that is then carried into the mold and formed, or trim the finished part before it is removed from the mold. These techniques are complex and require expensive tooling.

ROTATIONAL MOLDING

Rotational molding, known also as *rotomolding* or *rotocasting,* is a process for manufacturing hollow plastic products. For certain types of liquid vinyls, the term *slush molding* is also used. Although there is competition from blow molding, thermoforming, and injection molding for the manufacture of such products, rotational molding has particular advantages in terms of relatively low levels of residual stresses and inexpensive molds. Rotational molding also has few competitors for the production of large (> 2 m^3) hollow objects in one piece. Rotational molding is best known for the manufacture of tanks but it can also be used to make complex medical products, toys, leisure craft, and highly aesthetic point-of-sale products.

The Process

The basic principle of rotational molding involves heating plastic inside a hollow shell-like mold, which is rotated so that the melted plastic forms a coating on the inside surface of the mold. The rotating mold is then cooled so that the plastic solidifies to the desired shape and the molded part is removed. The mold rotation continues during the cooling phase so that the plastic retains its desired shape as it solidifies. When the plastic is sufficiently rigid, the cooling and mold rotation is stopped to allow the removal of the plastic product from the mold.

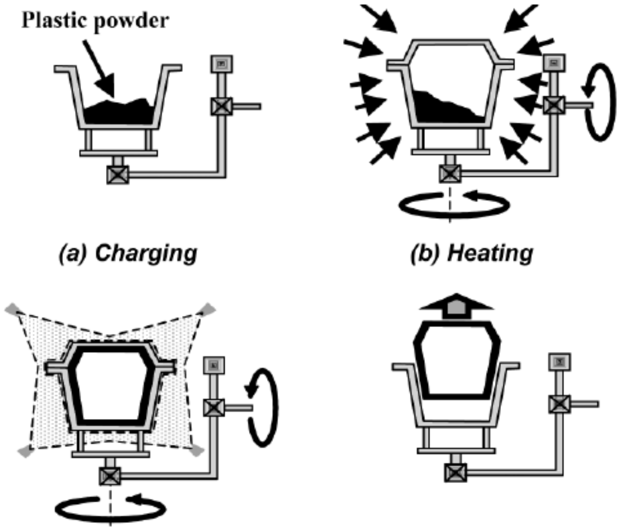
At this stage, the cyclic process may be repeated. The basic steps of

(a) mold charging,

(b) mold heating,

(c) mold cooling, and

(d) part ejection are shown in Figure.



(a) Charging (b) Heating

(c) Cooling (d) Demolding

Figure 1.1 Principle of rotational molding

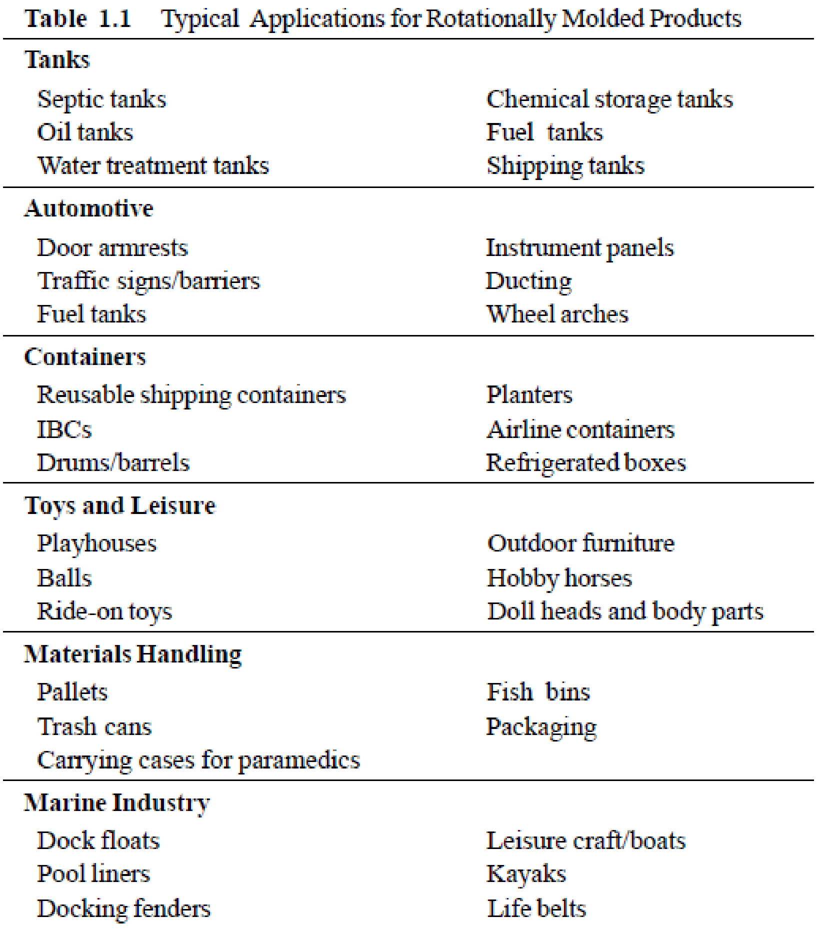


Table 1.1 Typical Applications for Rotationally Molded Products

Tanks	
Septic tanks	Chemical storage tanks
Oil tanks	Fuel tanks
Water treatment tanks	Shipping tanks
Automotive	
Door armrests	Instrument panels
Traffic signs/barriers	Ducting
Fuel tanks	Wheel arches
Containers	
Reusable shipping containers	Planters
IBCs	Airline containers
Drums/barrels	Refrigerated boxes
Toys and Leisure	
Playhouses	Outdoor furniture
Balls	Hobby horses
Ride-on toys	Doll heads and body parts
Materials Handling	
Pallets	Fish bins
Trash cans	Packaging
Carrying cases for paramedics	
Marine Industry	
Dock floats	Leisure craft/boats
Pool liners	Kayaks
Docking fenders	Life belts

Nearly all commercial products manufactured in this way are made from thermoplastics, although thermosetting materials can also be used. The majority of thermoplastics processed by rotational molding are semicrystalline, and the polyolefins dominate the market worldwide.

Advantages and Disadvantages

The main attractions of rotational molding are:

1. A hollow part can be made in one piece with no weld lines or joints
2. The end product is essentially stress-free
3. The molds are relatively inexpensive
4. The lead time for the manufacture of a mold is relatively short
5. Short production runs can be economically viable
6. There is no material wastage in that the full charge of material is normally consumed in making the part
7. It is possible to make multilayer products
8. Different types of product can be molded together on the one machine
9. Inserts are relatively easy to mold in
10. High quality graphics can be molded in

The main disadvantages of rotational molding are:

1. The manufacturing times are long
2. The choice of molding materials is limited
3. The material costs are relatively high due to the need for special additive packages and the fact that the material must be ground to a fine powder
4. Some geometrical features (such as ribs) are difficult to mold

Polymers as Powders and Liquids

The principal form for the vast majority of polymers used in rotational molding is as -35 mesh powder. Nearly all thermoplastic polymers are available as powders or as grindable pellets.

ROTATIONAL MOLDING MACHINES

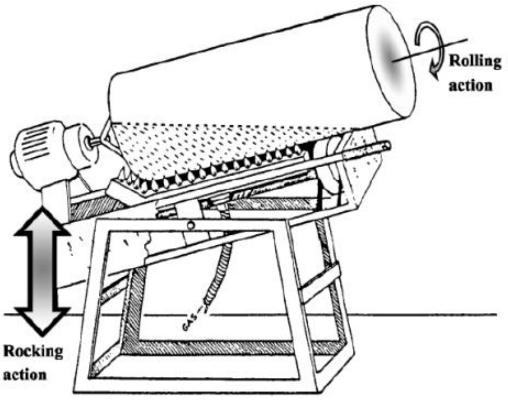
Since rotationally molded parts range in volume from 0.05 liters to more than 10,000 liters, generalization on machine types is difficult. The common aspects of the process are that the mold and its contents need to be rotated, heated, and cooled.

Some basic types of commercial rotational molding machines that are common across the industry are,

1. Rock-and-Roll Machines
2. Clamshell Machines
3. Vertical Machines
4. Shuttle Machines
5. Fixed-Arm Carousel Machine
6. Independent-Arm Machine
7. Oil Jacketed Machines
8. Electrically Heated Machines
9. Other Types of Machines

Rock-and-Roll Machines

This design concept of a rocking action about one axis (.rock.) and a full 360° rotation about a perpendicular axis (.roll.) was one of the earliest used for rotational molding. For a long time it has been thought that rock-and-roll machines are best suited to end products that are approximately symmetrical about a central axis, such as lamp-posts, canoes, and kayaks. the major advantage that it is easier to get services to and from the mold. It has also been found that the control over the wall thickness distribution can be just as good as that achieved on a biaxial rotation machine, for the vast majority of mold shapes. In a rock-and-roll machine, usually a single mold is mounted in the mold frame, the rotational speed is low (typically 4 rev/min), and the rocking angle is less than 45°. In the *rocking oven machine* the mold is surrounded by an oven, heated by hot air, and the oven rocks with the mold as shown in Figure 4.2. The rocking oven must contain appropriate burner assemblies, ducting and blowers, as well as an adequate shroud.



Typical rock-and-roll machine

Clamshell Machines

This machine is characterized by an oven that closes in a clamshell action over the mold. These machines have the attraction of a small floor footprint. The machine provides full biaxial rotation and has the advantage that the horizontal shaft can be supported at both ends. The molds are located on assemblies that are in turn mounted on turntables geared through the main shaft/axle. When the oven door is closed, the main axle rotates, turning the molds in a Ferris-wheel fashion and through gearing, the turntables rotate the molds about their axes. Heated air is circulated through the cabinet until the appropriate polymer temperature is achieved, then cooling occurs by cooled air and/or water mist. At the completion of the cooling cycle, the cabinet door opens with a book action, the molds are opened, and the parts are removed. The molds are then cleaned, inspected, and refilled with polymer and the next cycle begins.

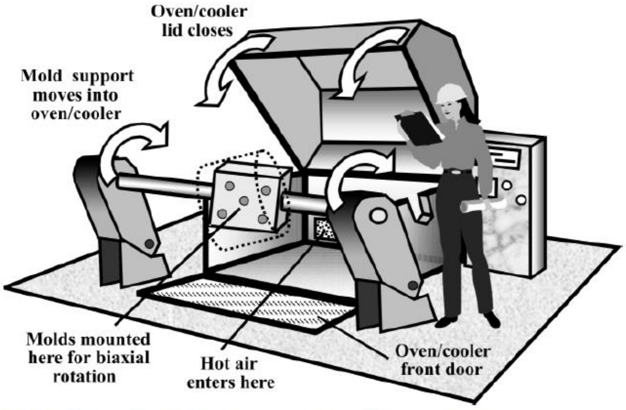
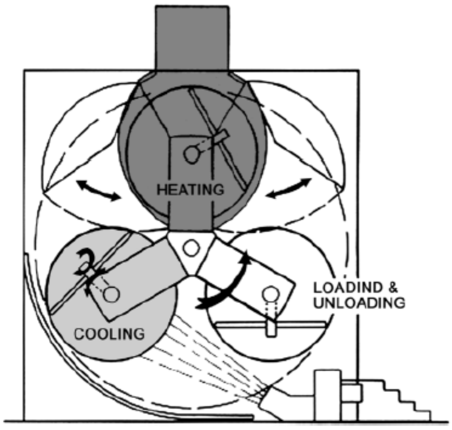


Figure 4.3 Clamshell type rotational molding machine

Vertical Machines

In this novel type of machine design there is a central horizontal axis and the molds are on arms that radiate out. At appropriate times, the central axis indexes the molds through 120° so that they move into the oven, the cooling area, and the service zone in sequence. The advantages of this design are that high volume production of small parts is possible in a small floor space.



Side view of vertical type rotational molding machine.

Shuttle Machines

Shuttle machines were developed as an attempt to conserve floor space. There are many types of shuttle machine designs. In one type of machine, the mold assembly, mounted on a rail carriage, is shuttled from the servicing/ cooling station to the oven station, and back again to the servicing/ cooling station. The efficiency of the shuttle machine is improved by using a dual-carriage design, whereby the oven is always occupied by the heating of a mold while the mold on the other carriage is being cooled/serviced. If the cooling/servicing time for the mold equals the heating time, then this system can approach the optimum in terms of maximum output rates.

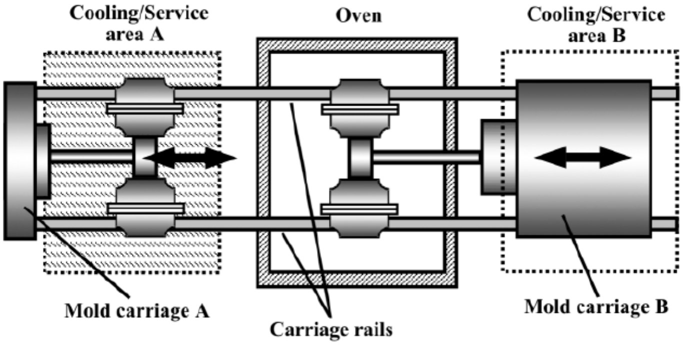
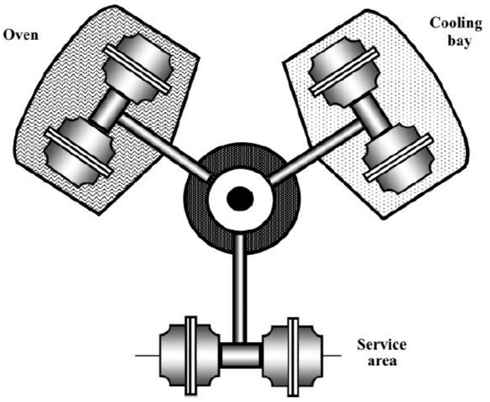


Figure 4.5 Shuttle type rotational molding machine, showing mold set B in oven and mold set A in cooling and service area

Fixed-Arm Carousel Machine

The carousel, turret, or rotary machine was developed for long production runs of medium to moderately large parts. It is now one of the most common types of machine in the industry. The earliest machines had three arms 120° apart that were driven from a single turret. All arms rotate together on fixed-arm machines. One arm is at each of the three stations, heating, cooling, servicing at all times, The carousel machine exemplifies the advantages of the rotational molding process in that different molds, and perhaps different materials can be run on each arm. It is possible to change the combinations of molds on one arm or on the other arms at regular intervals so that there is great versatility in production schedules. A disadvantage of the fixed-arm machines is that for optimum use, heating, cooling, and servicing times have to be matched. If they are not, then the cycle time is dictated by the slowest event and time is wasted in the other areas. This disadvantage has been overcome to some extent with the development of the independent arm carousel machine.



Fixed-arm carousel machine

Independent-Arm Machine

Recently, independent-arm machines have been developed in an effort to improve the versatility of rotary machines. The current machines have five designated stations, and can have two, three, or four arms that sequence independently of one another. The first key to versatility is having fewer arms than stations. This allows the operator to designate the empty stations as auxiliary oven stations, auxiliary cooling stations, and/or to separate the loading and unloading steps in the servicing stations. Although these machines are more expensive than the other machine designs discussed above, they are ideal for custom rotational molding operations.