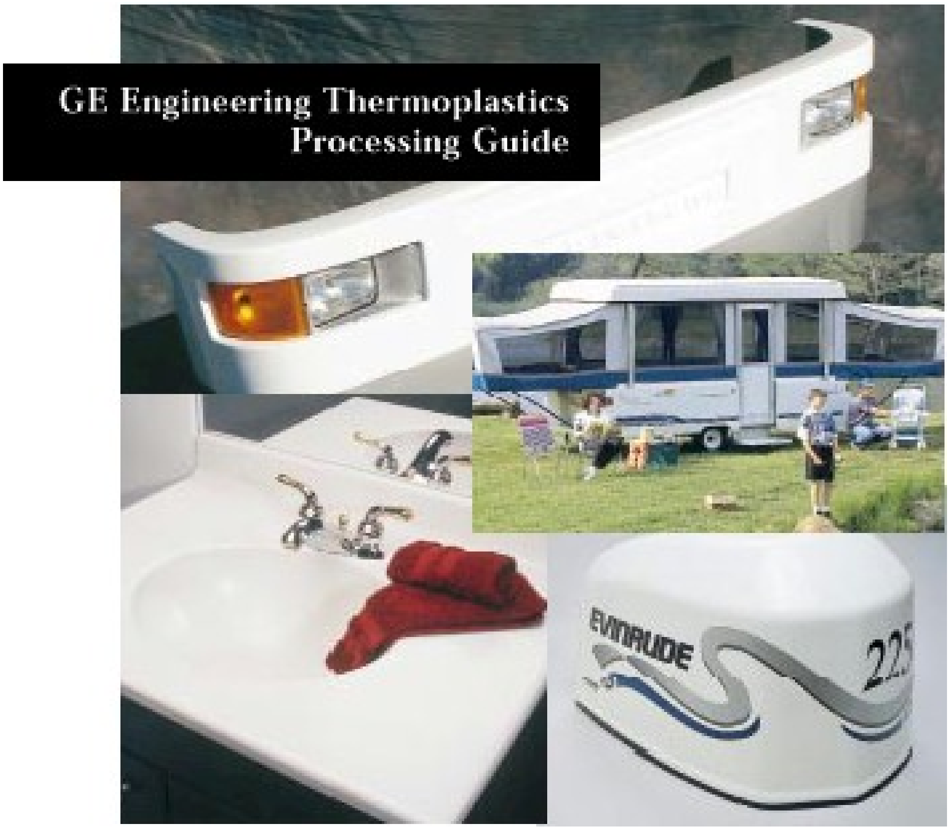
GE Plastics

Thermoforming Processing Guide



This guide provides information on thermoforming, a process that uses heat and pressure to transform plastic sheet and film into finished parts. This is meant to be a hands-on guide intended for those processors who want to increase their productivity and, by doing so, drive greater profitability through the production of higher-quality parts at lower costs.

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Overview

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Because accurate and timely information is vital in any business strategy, the guide includes information on GE Plastics' extrusion and thermoforming resins, by far the industry's widest selection. You'll also find helpful information on the thermoforming process, various forming methods, sheet quality, equipment, drying and heating, mold design, and part design.

Though thermoforming represents just one of many options for shaping plastics into finished parts, the tremendous size of the total market assures that sizeable opportunities will continue to exist. Thermoforming has grown impressively over the past few years, and that trend is expected to continue.

Thermoforming offers many potential advantages over other processing methods. Often, large applications with relatively small production runs are not economically feasible using injection molding. From a cost/quality standpoint, thermoforming may be the only practical processing method.

Thermoforming equipment and molds typically cost much less than that required by other processing methods. A wide range of large, thin-walled, lightweight parts are not only possible but also practical with thermoforming. Moreover, many processors can realize these benefits with a relatively low initial investment.

Application Opportunities

The ability to produce large parts with thin walls in a variety of shapes has led to the use of thermoforming in many diverse applications, including:

- Bath and shower furnishings,
- Spas,
- Components for recreational vehicles,
- Siding,
- Windows,
- Consumer products,
- Appliances and housewares,
- Components for specialty transportation,
- Automotive components,
- Marine components,
- Lawn and garden,
- Lighting, and
- Packaging.

GE Plastics' Resins

From the first introduction of engineering thermoplastics right through to the most recent technological advan
GE Plastics has been and remains the industry leader and innovator. As the world's leading supplier of engir
plastics, GE Plastics offers an unmatched spectrum of base resin chemistries that can be used for thermofor

The GE marketbasket of products includes: LEXAN® PC resins, CYCOLAC® ABS resins, GELOY® ASA weatherable resins, CYCOLOY® PC/ABS resins, NORYL® modified PPO® resins, ULTEM® PEI resins, VALOX® PBT resins, ENDURAN™ surface material, and XENOY® PC/PBT resin alloys

Each of these polymers continues to evolve, many having spawned advanced copolymers, alloys, and composites. See Table 1 for Grade Characteristics and Typical Applications.

PRODUCT	CHARACTERISTICS OF SPECIFIC GRADES	TYPICAL APPLICATIONS
CYCOLAC® ABS Resin		
Reliable performance without the cost or properties designers and manufacturers might not need. This versatile terpolymer is available in a wide variety of grades, offering a broad range of combinations of outstanding toughness, durability, and dimensional stability.	Ease of processing, very good color stability, low water absorption, UL94 rated, very good surface, controlled low gloss, chemical resistance	RV interiors, marine components, spa and tub surrounds, automotive trim, luggage cases, medical housings, card stock, and appliance parts
CYCOLOY® PC/ABS Resin		
Offering a balance of performance, processability, and cost, this versatile resin alloy provides low-temperature ductility, plus excellent impact resistance and flow, practical heat resistance, and very good aesthetics.	Very good processability and ductility, impact and heat resistance	Transportation interiors, business equipment, and appliance parts
GELOY® ASA Weatherable Resin		
Maintains a leading place in the ranks of weatherable resins. Made for outdoor life and use, GELOY resins offer a combination of toughness, color, and property retention.	Very good weatherability, high impact strength, light and dark colors	RV components, marine market, automotive exteriors, outdoor electrical housings, and spas, pools and steps
LEXAN® PC Resin		
The industry's "original" polycarbonate, discovered by GE in the 1950s, offers outstanding impact resistance, excellent dimensional stability, and crystal clarity or rich color. Extrusion and thermoforming grades set new standards in durability and consumer appeal.	Exceptional melt strength, high impact strength, glass-like transparency and gloss, FR, UV, FDA. Glass-reinforced grades available	Glazing, skylights, graphic films, food containers, transportation windows, and sign displays

PRODUCT	CHARACTERISTICS OF SPECIFIC GRADES	TYPICAL APPLICATIONS
NORYL® PPO® Resin		
Market-tailored performance, ease of processing, and enhanced productivity mark this versatile material. NORYL resin is a time-proven product that can often deliver needed performance while remaining cost effective.	UL94 rated, paintable, good structural properties for load-bearing extrusions, available in grades with HDT between 180 °F and 265 °F, hydrolytic stability, NORYL GTX® resins offer excellent resistance to typical hydrocarbons	High-temperature food packaging, roofing, truck fairings, computer enclosures, asphalt truck bed liners, auto interiors, and beverage cases
ULTEM® PEI Resin		
The product of unique polyetherimide chemistry, ULTEM resins offer outstanding mechanical performance, broad chemical resistance, plus excellent dimensional stability and creep resistance.	200 °C (392 °F) HDT, UL RTI rating of 170 °C (338 °F), unreinforced high strength, low creep and CTE, broad chemical compatibility, UL94 rating, autoclavable, meets FAA flammability standards, FDA, EEC, USP Class VI, tripartite compliant	Medical trays, commercial food service trays, catering carts, packaging, aircraft interiors, dishwasher safe, lighting reflectors, and high temperature films
VALOX® PBT Resin		
Excellent dielectric strength, low water absorption, low warp, plus heat and chemical resistance. In addition, this high-performance PBT can provide excellent design advantages and process reliability.	Oil/grease resistance, high surface gloss, very good electrical properties	Outdoor electrical enclosures, packaging, lidding
ENDURAN™ Surface Material		
One-of-a-kind, mineral-filled polymer offering the quality look and feel of solid surfacing in a full palette of colors. This material is used for kitchen countertops, bathtubs, shower pans and surrounds, and sinks. It is also chip resistant and easy to clean.	High-quality appearance, chip resistant, easy to clean	Kitchen/bath surfacing

PRODUCT	CHARACTERISTICS OF SPECIFIC GRADES	TYPICAL APPLICATIONS
XENOY® PC/PBT Resin		
The PC amorphous aspect of this alloy combines high- and low-temperature durability and dimensional capabilities. The PBT crystalline component adds enhanced chemical resistance. XENOY resin combines strength, chemical resistance, and dimensional stability in a unique package.	Exceptional low-temperature impact, good chemical resistance, very good color and UV stability	Automotive trim and outdoor vehicle enclosures
VISUAL*fx*™ Portfolio		
A growing portfolio of resins designed to meet the growing demand for enhanced aesthetics and color in the design of products. Customers can use our VISUAL*fx* products to gain market-share and promote brand recognition. GE Plastics is marketing its decorative resins under the VISUAL*fx* name.	Light diffusion resin (provides a sense of depth), Magix™ resin (a sparkling metallic flake), Intrigue™ resin (produces a color shift effect)	Computer and business equipment housings, consumer products (disposable razors, appliances, housewares), telecommunications products, automotive components, toys, cosmetics

Table 1. GE Resin Grade Characteristics and Typical Applications.

Types of Molds

Of the many elements that contribute to a successful thermoforming operation, perhaps the most important is mold design. Well-designed molds made of the correct materials will promote consistent quality in the finished parts. Conversely, the wrong materials employed in poorly designed molds are likely to compromise the work of even the most experienced processor.

The thermoforming process makes use of many types of molds. In fact, the low cost of thermoforming molds and the short lead times required for tooling can give this method great competitive advantages over other processing options.

Generally, only one side of the mold is needed to form parts from heated sheet or film. This can be a male mold or a female mold, depending on the shape of the finished part, how the part will look (aesthetics), and the specific forming process used. The deeper the part being formed, the more critical the choice between male and female molds.

For shallow, low-profile parts, the reduction in wall thickness is typically minimal. Mold selection thus depends more on part appearance. If intricate mold details must be duplicated, the side of the sheet that touches the mold should be the one that becomes visible.

Sometimes, a part requires a rounded appearance or the sheet may have a textured surface that could be affected when it touches the mold. In these instances, the side that doesn’t touch the mold should be one that’s visible in the formed part. Greater dimensional control is generally found at the mold surface side.

It probably can’t be emphasized enough: building a quality mold is paramount to thermoforming success. Before mold building, four questions need to be asked and seriously considered:

1 What mold design will be best suited to produce the given part?

2 What material will work best?

3 What are the design requirements of the finished part?

4 Will thermoforming require plugs and/or ring assists?

Only when these questions are sufficiently answered can the mold be properly designed.

Male and Female Molds

A male mold is characterized by one or more raised elements (projections). The heated sheet is drawn over the projection(s) to form the part.

Male and female molds produce different wall thicknesses. Male molds typically produce parts formed with more thickness at the top. Parts formed using female molds show greater wall thickness around the edges.

Where deep draws are needed (up to 3:1 depth/diameter draw ratio), male molds are generally employed. A 3:1 depth/diameter ratio means that the thickness of an area of the part is just one-third of the original sheet thickness. The depth/diameter draw ratio in female molds is typically limited to 2:1, unless the sheet is prestretched.

For irregularly or oddly shaped parts, the draw ratio is difficult to establish. Usually, it is calculated as the ratio of the maximum cavity depth to the minimum span across the edges of the unformed sheet.

The area draw ratio is expressed by the ratio of the original sheet area (as measured within the mounting frame) to the surface area of the part after it has been formed. These values correspond to the biaxial stretching of the sheet. However, they only approximate the average wall thickness.

The linear draw ratio is determined by the length of a projected line passing through the deepest depression of the part compared to the length of that line on the original sheet. This ratio indicates the highest unidirectional stretching the sheet will have to endure.

Matched Molds

Matched molds feature both male and female halves. The two mold halves are mounted over each other and are closed over the heated sheet, either pneumatically or mechanically. The sheet is shaped as the two sides join together. Matched-mold forming can provide excellent reproduction of intricate details, such as lettering or surface textures. This thermoforming method has found widespread use in forming plastic sheet for various packaging applications and is the best way to maintain wall tolerances.

Although vacuum or air pressure is seldom applied in match-mold forming, the mold must be adequately vented. The forming process is rapid; the material must remain in that section of the equipment until most of the heat is removed (see the section on cooling under “Removing and Cooling the Finished Part” in Thermoforming a Finished Part Chapter.)

Multiple Molds

Multiple molds form several parts in the same cycle.

Typical Multiple-Mold Layout

A multiple-mold configuration generally has two decided advantages:

- Greater output, and
- Reduced trim scrap.

Male molds in the multiple-mold layout should typically be spaced equal to 1.75 times the mold height. If spacing is tight, webbing can occur. Female molds should be spaced together as close as possible.

Commonly Used Mold Materials

Thermoforming uses relatively low temperatures and pressures. Because of this, a variety of materials can be used for making thermoforming molds. Molds can be made out of wood, plaster, plastic, aluminum, steel, sprayed metal, or layered metal. The choice of material depends on the number of production parts required and their quality.

Wood Molds

Molds made of well-dried hardwood are often used for low-production parts. Wood has a low thermal conductivity, and it won’t “chill” the sheet as it makes first contact with the mold. Wood molds, which must be preheated, are most commonly used for small production runs and are not advised for fast, repetitive forming in large volumes because of the inadequate heat rejection.

Plaster Molds

Inexpensive, easily shaped molds can also be cast from plaster. Plaster molds are typically used for prototyping or on parts with small runs. Poor durability, lack of heat conductivity, and the inability to control temperature make plaster molds ill suited for large production volumes.

Plastic Molds

More durable and temperature-resistant molds for rapid forming cycles can be built using phenolic or epoxy resins. These molds offer excellent dimensional stability; good abrasion resistance; and a smooth surface. Also, most plastic molds can be inexpensively patched and repaired.

Plastic molds can be provided with air passages and cooling tubes, making them useful as mold blanks. Plastic molds do not conduct heat very well. Because of this, they should not be used where the plastic sheet must be rapidly cooled for fast cycles.

Aluminum Molds

For long production runs, cast or machined aluminum molds are usually chosen. They are prepared by casting or by layering and their surfaces can be textured or polished to a high gloss.

Hard metallic coatings or applying polytetrafluoroethylene can improve the durability of the mold and the draping of the sheet. Coatings can also help maintain consistent sheet thickness.

Aluminum conducts heat well. Heating and cooling are quickly done versus less conductive materials, allowing faster cycle time. The high thermal conductivity of the metal makes it necessary to preheat the molds prior to forming. Hot water can be circulated through the cooling channels or radiant heat can be used. For rapid forming, aluminum molds must be properly cooled. Thermostatic controls should be used.

Steel Molds

Durable molds for most simple parts can be machined from standard steel stock. Steel molds are generally easy to plate but are usually expensive to build. This needs to be weighed against part design and production volume in evaluating manufacturing economies.

Sprayed Metal Molds

Sprayed metal molds have metal shells reinforced with resin-filled backing to provide reinforcement and rigidity. Sprayed metal molds can be made of a range of metals, including aluminum, copper, nickel, steel, tin, and zinc. A metal spray is generally used to increase mold strength.

Sprayed metal molds are extremely long lasting and durable and typically show little wear, even in production volumes in the hundreds of thousands. Sprayed metal molds are also excellent for reproducing fine details from the mold to the formed part.

Layered Metal Molds

These permanent metal molds, sometimes referred to as electroformed molds, are produced using successive layers of copper, nickel, and chromium. The metal layers are formed into a shell. These molds can achieve precise mold details and produce parts with excellent surface finish.

The layered metal shell is usually reinforced with low-temperature, non-ferrous alloys such as zinc.

Factors That Can Affect Mold Design

Technological advances in tooling and thermoforming machines, plus the development of improved, high-performance engineering thermoplastics, have made thermoforming one of the fastest growing methods for processing plastics. The following mold design guidelines are offered to assist processors in producing finished products that combine high strength, pleasing appearance, and reliable performance.

Mold design involves several key factors, including:

- Radii,
- Draft angles,
- Undercuts, and
- Vacuum holes.

Here are some important mold design factors to keep in mind:

- Draft Angle – Minimum draft angle should be two to three degrees on a male mold and one-half to one degree on a female mold. Molds with textured surfaces may need more draft so the part will release without scratching.

- Vacuum Hole – The diameter of the vacuum hole should not exceed 50 percent of the part thickness. Holes that are too large can cause blemishes. If more vacuum force is required, put in additional holes rather than enlarge existing ones.

- Undercuts – Generally, undercuts should be avoided. However, if they are necessary, removable inserts or cam-action mold parts should be used.

- Shrinkage – Molds must be made oversized to allow for shrinkage. Usually, an allowance of 0.003-0.005 in./in. (cm/cm) on male molds and 0.005-0.006 in./in. (cm./cm.) on female molds is adequate. The material, its coefficient of thermal expansion, and part design all affect shrinkage.

- Radii – Radii on ribs and fillets should not be less than the minimum part thickness. The radii should be as as four times the wall thickness in areas of high loading or where extra stiffness is required.

- Draw – In simple forming, depth of draw is usually limited to the width of the part. Greater draw ratios are often possible using more sophisticated forming techniques or in cases where a uniform wall thickness is not critical. The depth an engineering thermoplastic material can be drawn helps determine the appropriate thermoforming technique for a given application. For draws with depth-to-width ratios of less than 2:1, male drape forming generally gives a more uniform wall thickness. For deep draws (greater than 2:1), billow predraw and plug-assist female forming is recommended. A true draw ratio is expressed as the surface area of the part divided by the sheet area of blank (within part perimeter). Thus, the average part thickness is the starting sheet thickness divided by the draw ratio. Often, a “quick ratio” of width-to-depth is used. .

- Margin – The area of the margin of sheet required between the clamp frame and the part to be formed ranges from 15 percent to 40 percent of the product area. The exact percentage depends on part geometry and design complexity.

- Plug Assists – Plug assists pre-stretch the sheet and assist in forming. Plugs are designed to conform to the cavity. Compared to the cavity, plugs should be 10 percent to 20 percent smaller in length and width to allow for clearance between the sheet and the mold. Moreover, the plug should have no sharp corners.

- Ring assists – Ring assists help prevent webbing in multicavity male molds. They generally require no temperature control.

Part design usually accounts for a small piece of a project’s development costs but affects a huge part of the production costs. Production gains are available to the designer who intelligently uses engineering thermoplastics and designs them for manufacture and assembly. One of the truisms of the successful design of thermoformed parts is this: the probability of success is greatly enhanced by executing well-conceived product design.

Design for Manufacturing and Assembly

Designers generally make use of engineering thermoplastics not so much for simple one-to-one replacement of metal, but rather employ plastics to consolidate parts and build more function into the finished part. By considering manufacturing and assembly steps in the initial design equation, the opportunity exists to engineer both the part and the production process at the same time.

This approach can allow design engineers to make the greatest use of engineering thermoplastic material.

Basic Design Guidelines

1. Minimize the number of parts. Fewer parts can reduce overhead by eliminating documentation (drawings, material specifications, purchase orders, etc.), speed assembly, and improve quality.
2. Minimize assembly surfaces. Multiple assembly surfaces generally add time and motion to the assembly sequence. Fewer surfaces = faster assembly
3. Design for Z-Axis Assembly. The simplest and most preferred assembly motion is typically straight down (the Z-axis). This uses gravity to assist the assembly.
4. Improve assembly access. Provide a “clear view” of assembly operations. Avoid parts or assembly sequences that require tactile sensing for installation. Such “blind” assembly can expose the manufacturing process to significant quality risks.
5. Maximize part symmetry. The more symmetrical the part, the easier it is to handle.
6. Improve part handling. Where possible, avoid flexible parts, such as wiring for parts that require two-handed manipulation.
7. Avoid separate fasteners where possible. Fasteners are difficult to feed and are a major barrier to efficiency. Better designs incorporate as much of the fastening function directly into the part as is feasible.
8. Drive toward modular design. Modular design simplifies final assembly because there are fewer parts to assemble. Also, try to limit subassemblies.

Reproducing Fine Details in the Mold

In reproducing intricate details from a mold onto a heated sheet, good results can often be obtained using straight female vacuum and male drape thermoforming. Part design determines what technique to use. A good general guideline is to use female vacuum forming for outside detail and male drape forming for inside detail.

These welding masks, molded in CYCOLAC resin, demonstrate the ability of thermoforming to reproduce fine detail.

Draft Angles

Thermoformed parts from female molds usually do not have cores that restrict the normal shrinkage of the part as it cools. The shrinkage of a three-dimensional part actually pulls the outer walls of the formed part away from the side walls of the die that are perpendicular to the open face of the die. This is very useful, since it allows some parts to be designed with little or no sidewall draft. This can provide a major benefit, particularly over injection-molded parts, which are prevented by the core from shrinking away from the cavity.

Most thermoformed parts will be easier to produce if they are designed with side draft angles of one-half, one, or even five degrees.

As a male mold cools and shrinks, it draws down tightly on the mold surfaces. These inside surfaces should be smooth. They should have draft angles of at least one degree per side, and preferably five degrees.

The corners on these kinds of inside surfaces should be given the largest possible radii. This will help avoid the "stress concentrator effect." It will also help reduce the molded-in stress that will occur as the shrinking material draws against the edges of the mold.

The designer should keep two points in mind:

- Any draft is better than no draft at all, and
- The larger the draft angle, the better for the finished part.

The designer should also recognize that tough, self-lubricating resins will be easier to remove from female m

Brittle, nonself-lubricating materials with low shrinkage rates will be more difficult to eject from the mold.

Remember that no two plastic resins are the same. Each material has its own design requirements.

Stiffening

Satisfying the stiffness and rigidity requirements for any application is crucial. Flex modulus is the best expression of rigidity.

Stiffness can be improved through a number of design techniques. One approach is to keep the part geometry the same and use a higher modulus material. Of course, all the application requirements, including cost considerations, need to be weighed.

A more practical approach may be to change the part design to increase the section modulus. This can be done by incorporating design features such as:

- Ribs,
- Gussets,
- Corrugations, and
- Grooves.

These features are known as stiffeners.

How Stiffeners Work

Stiffeners increase not only the stiffness but also the load-bearing capacity of the part. They do this by locating material away from the neutral axis. This design technique increases the moment of inertia (second moment of area) of the cross-section. The basic formula for moments of inertia is the integral of the distance from the neutral axis squared over the area:

$$I = \int y^2 da$$

Thus, the distance from the neutral axis contributes to stiffness in a squared manner, while material modulus and area only contribute linearly.

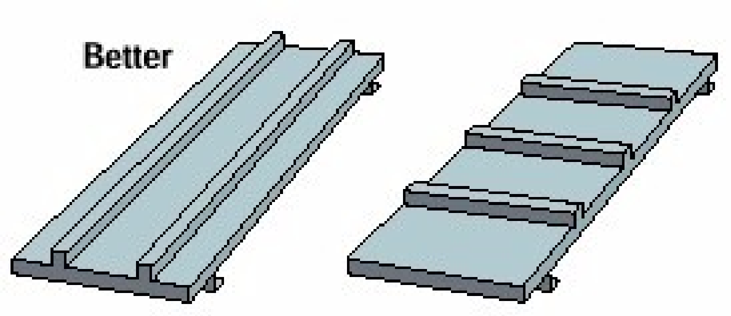
Ribs

Ribs are the most commonly used stiffener. When designing with ribs, there are several considerations:

- In some applications, ribs can interfere with the functioning of the part or compromise part aesthetics.
- A stiffening rib can significantly reduce deflections and redistribute stresses.

Rib Orientation

To promote maximum stiffness, ribs should be oriented along the axis of bending. This is illustrated by a long thin plate, which is simply supported at the two ends.



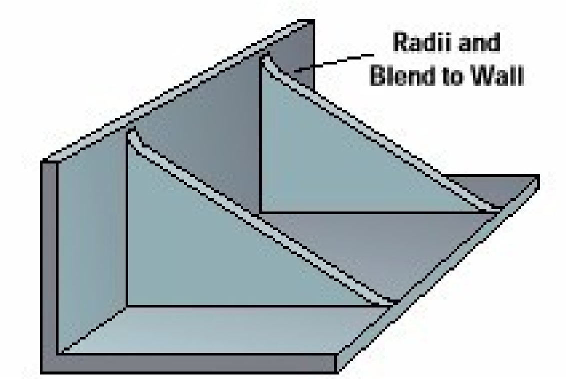
Ribs added in secondary operations along the axis of bending increase stiffness.

If ribs are added which run along the long direction of the plate, the part stiffens considerably. However, if ribs are added across the beam, parallel to the short sides, the effect on stiffening is negligible. Similarly, if a flat plate is loaded by torsion, diagonal ribs will be more helpful than perpendicular ones.

While the stiffness is proportional to the moment of inertia, strength is proportional to I/C in bending, with C being the distance from the neutral axis. The effect of changing the height is moderated as C gets larger.

Gussets

Gussets are stiffeners often designed into plastic parts at points of attachment, support, or contact with other components. Gussets can greatly reduce localized regions of large deflection.

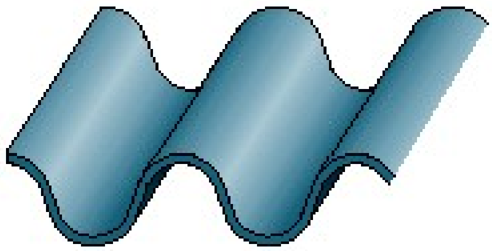


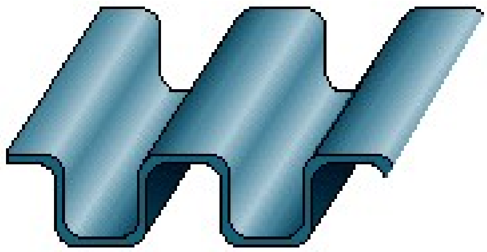
Gussets, also added in secondary operations, can be effective in reducing localized regions of part deflection.

Regarding wall thickness at intersections, draft angles, and orientation, gussets should be designed using the same principles that are discussed in the Ribbing and V-Groove sections. Generally, gussets incorporate the “triangular brace” concept to provide stiffness and strength by transferring loads from one detail to another. A gusset of this type can significantly reinforce a contact area and can distribute stress more evenly in the part. As with ribs, gussets should be designed with the direction of the tool pull in mind.

Corrugations

Designers frequently employ corrugations to provide stiffness to flat surfaces. Corrugations are relatively efficient stiffeners because they do not use large amounts of additional material and do not require additional cooling time. However, corrugation often cannot be used because it provides an uneven top and bottom surface.





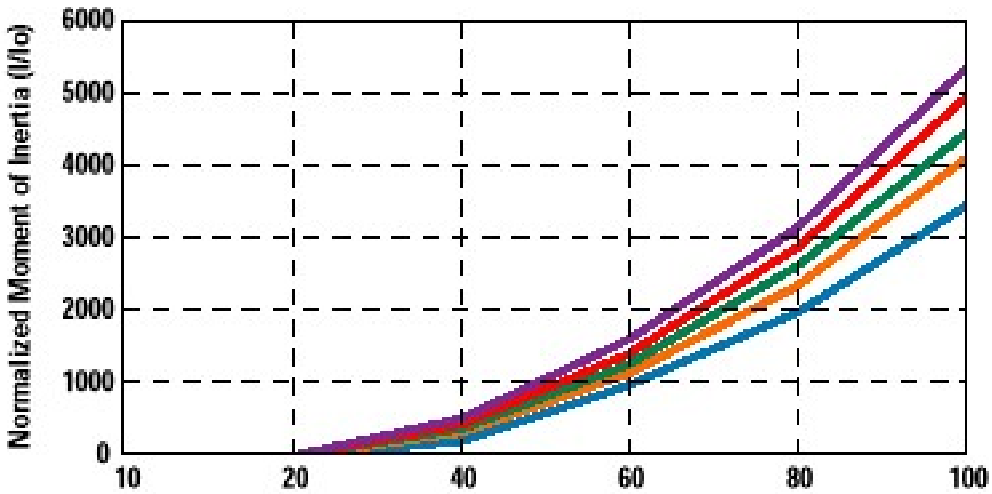
As with ribs, corrugation provides stiffness by increasing the average distance of material from the neutral axis of the part, thereby increasing the moment of inertia (the second moment of area). Stiffness is only increased in the direction of orientation.

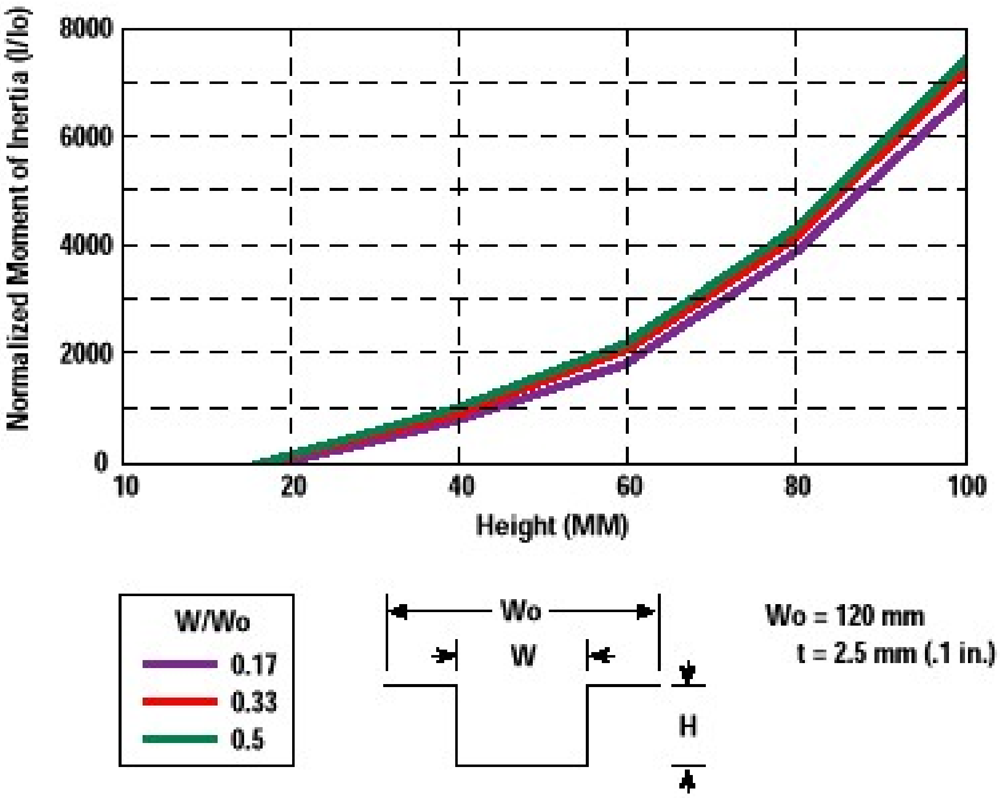
To reduce this effect, large deflections often dictate that parallel corrugations be periodically connected by stiffeners at right angles. Intersections of corrugations with other stiffeners are usually straightforward to design, bearing in mind the material mass and radius requirements for all inside corners.

A corrugated design can be very effective in stiffening a wall in the direction of the corrugation. The design moves material away from the neutral axis and increases the moment of inertia.

The graphs show the normalized moment of inertia versus the height of a corrugation.

The moment of inertia was figured for a corrugated design and then normalized by the moment for a flat profile with the same wall thickness. Obviously, the height of the corrugation has a dramatic effect on the moment of inertia.





While the stiffness is directly proportional to the moment of inertia, strength is proportional to I/C in bending, with C equal to the distance from the neutral axis. The effect of changing the height is moderated somewhat as C gets larger.

V-Grooves

V-grooves may be designed into parts as a way to greatly increase stiffness. V-grooves are considered to be effective stiffeners because they do not use large amounts of additional material and do not require additional cooling time during molding. However, V-grooves often cannot be used because they disrupt the top and bottom surface.

V-grooves

As with ribs, V-grooves provide additional stiffness by increasing the average distance of material from the part's neutral axis, increasing the moment of inertia (second moment of area). V-grooves increase stiffness in the direction of the run; however, they are ineffective when employed perpendicular to the direction of the orientation. Intersections of V-grooves must be carefully designed to avoid large material masses and reduce the loss of stiffening effectiveness.

Equivalent Stiffness

When redesigning a part in a new material or when comparing design options, it is often desirable to design for equivalent stiffness. The method used to do this depends on the type of loading – tensile, compressive, bending, or shear. The two most common types of rigidity used for equivalent stiffness are tensile and flexural, described below.

Tensile

When designing for equivalent stiffness in tension, the designer must take into account part geometry and material properties.

- Hand calculation – This is only meaningful for parts that have a relatively constant cross-sectional area perpendicular to the applied load. The product of the cross-sectional area and the material's elastic modulus for the two alternate designs must be matched. This method should be used only in cases where a simple linear load-deflection is anticipated (for relatively simple geometries with relatively small elongation below the proportional limit of the material). Equivalent stiffness can be achieved when the area and material's elastic modulus is known for one design, and either the modulus or the cross section is known for the second design (the second can simply be solved from the first: $A_1E_1 = A_2E_2$).

Flexural

When designing for equivalent stiffness in bending, part geometry and material properties must be factored in. The geometric and material parameters will determine which analysis is appropriate.

- Hand calculation – The product of the moment of inertia (the second moment of area) and the elastic modulus for the two alternate designs must be matched. This method should be used only in applications where a simple linear load deflection is expected. Equivalent stiffness is achieved when the moment of inertia (second moment of area) and the material's elastic modulus are known for one design, and either is known for the second design: $E_1I_1 = E_2I_2$.

The moment of inertia (second moment of area) can be increased or decreased by changing the amount of material or by altering the material's average distance from the neutral axis.

Corner Radii

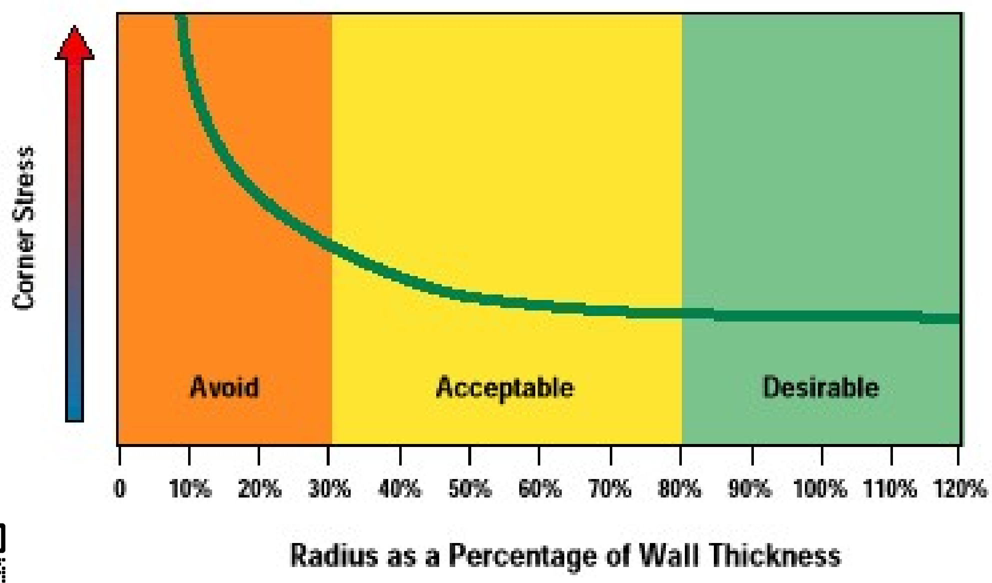
In producing a quality part, corner radii must be properly proportioned. Corner radii serve three basic functions:

1 They simplify manufacturing.

2 They strengthen the corner.

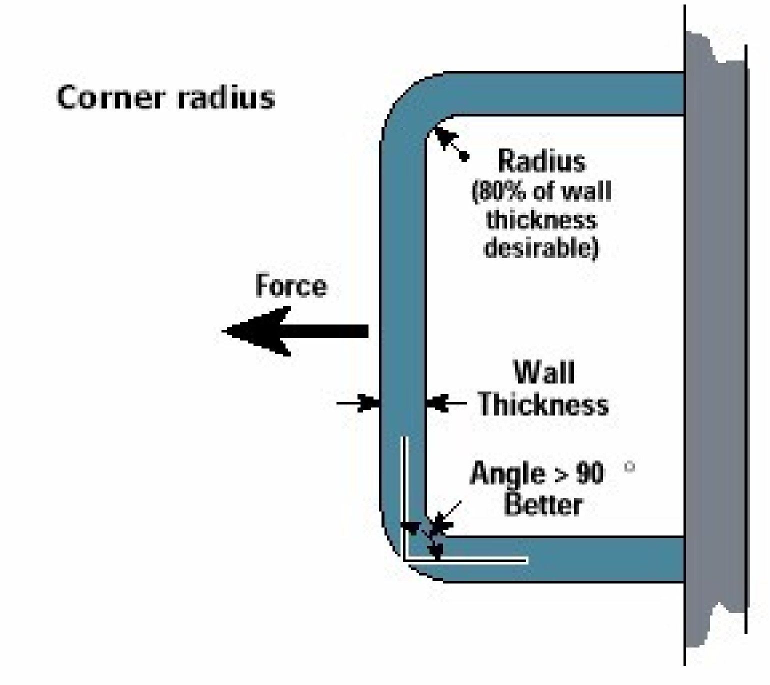
3 They redistribute stress.

Whenever the size of the inside corner radius of a plastic part is less than 75 percent of the wall thickness of the part, there will be a gradual increase in stress.



There will be a very rapid increase in stress when the inside corner radius is less than 25 percent of the thickness of the wall to which the radius is attached.

Considering these facts, the inside corner radius of a thermoformed plastic part generally should not be less than 25 percent of the wall thickness.



For maximum strength, the radius should be at least 75 percent of the thickness of the wall to which it is attached.

The designer must also remember that each plastic material is unique. Each must be handled in a way that reflects these differences. Be sure to obtain complete information from the material supplier on the engineering thermoplastic being considered for a particular application. GE Plastics' Customer Solutions Center can provide assistance.

The shape of a part leading up to a corner also affects both sheet thinning as well as the size of the corner radius that can be formed. A corner with an angle more than 90° is preferred. Angles less than 90° should be avoided where possible.

The proportions chosen for the corner radius on a plastic part will significantly impact the part's strength. The strength of the corners is determined primarily by the size of the inside radius. Designers therefore tend to specify the inside corner radius of a plastic part.

In the case of thermoformed parts, only that corner on the side of the part that comes into contact with the die can be accurately controlled. The designer must keep this in mind when specifying the corner radii on pressure-formed parts.

Poorly designed corners can cause an excessive amount of mechanical stress in the part and greatly reduce both the service life and structural strength of a part.

Alternate Methods for Adding Stiffness

In thermoforming, it can be difficult to design parts with ribs or stiffeners. In these instances, parts may need stiffened in other ways. This can be done with bonded doublers, fiberglass spray-up, and foaming-in-place.

Lavatory sink bonding ENDURAN surface material to a foam and wood substrate. A variety of adhesives can be selected for bonding to different substrates.

Bonded Doublers

Two thermoformed parts are bonded together. Parts can be joined with adhesives, ultrasonically, or stapled. To be effective, at least one portion of the bonded part should have angles close to 90°.

Fiberglass Spray-up

The spray-up process involves thermoforming a thin skin (0.035 inches) and spraying the reverse side with a thin layer of polyester resin reinforced with chopped fiberglass.

Foaming-in-place

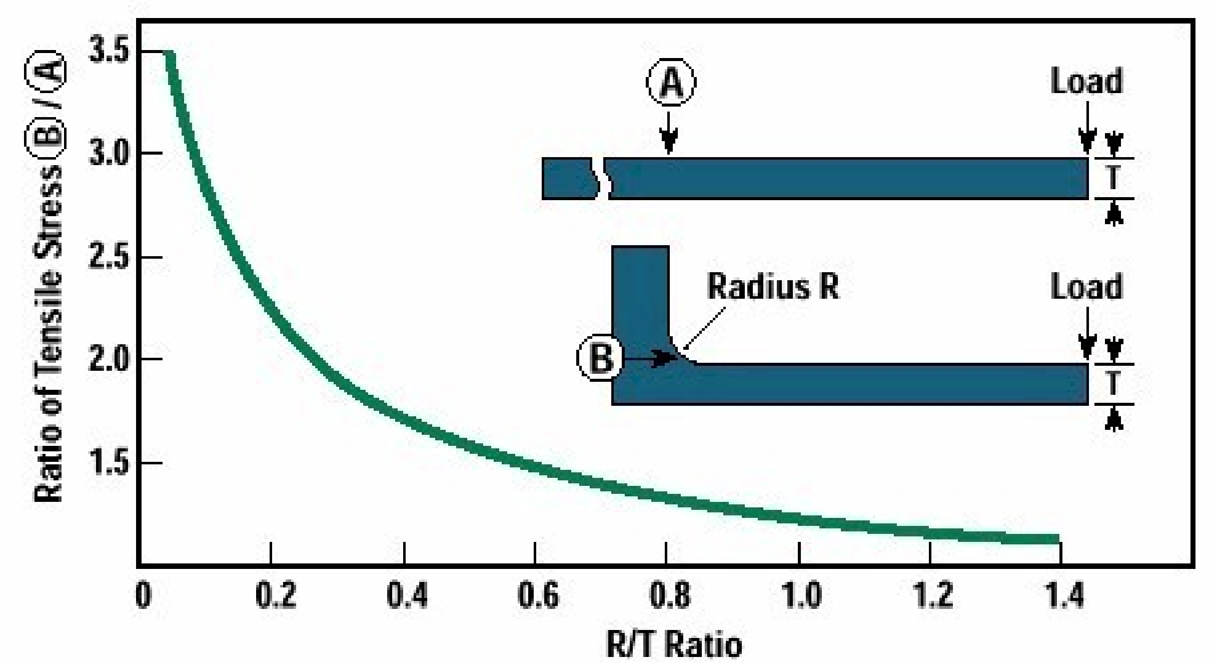
In this process, parts are thermoformed and trimmed to size. The outside part is then placed into a female fixture. Polyurethane foam is applied. The inside thermoformed part is then placed in position, and a mold that matches the opposite side is clamped into place. As the foam expands, it chemically bonds to the sides of the parts, eventually filling up the cavities between the two.

Stress Concentration Factors

Stress concentration factors are a standard tool for design engineers. Developed from empirical data, these factors are used to approximate the stress levels in areas that hand calculations cannot evaluate.

Stress Concentration Factors depend upon the part design only – that is, they are the same, regardless of the type of material being used.

Since engineering thermoplastic resins generally have relatively low stress limits compared with metals, consideration for Stress Concentration Factors is an important step in the design of thermoformed parts.



Stress concentration factors.

Allowing for Shrinkage

Good part design allows for shrinkage, including shrinkage that occurs in and outside the mold.

Shrinkage in the mold – Shrinkage occurs during cooling and varies with part design, the resin being used, and processing parameters. Shrinkage is usually less of a concern in male drape forming than it is during female vacuum forming.

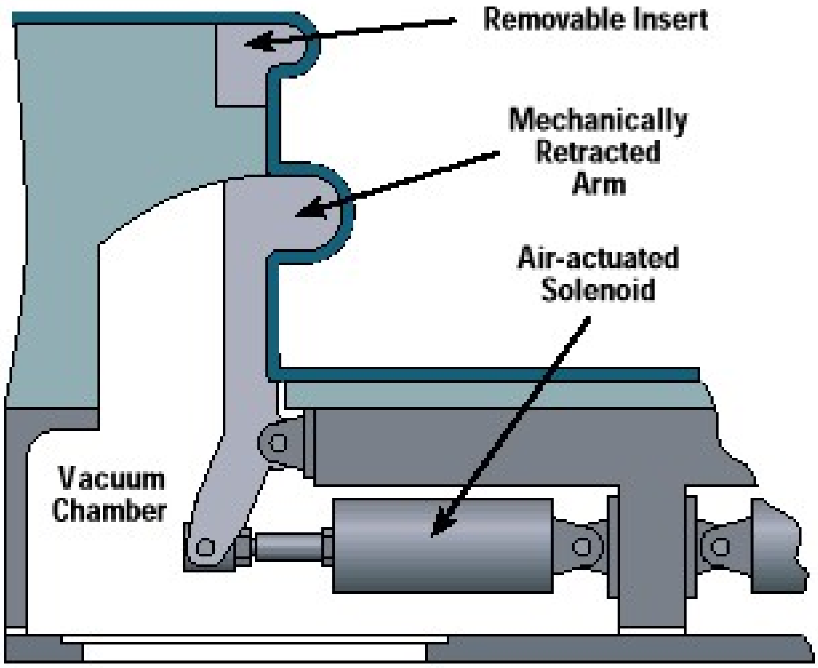
Shrinkage outside the mold – After being removed from the mold, the part will shrink as it cools. This shrinkage stops when temperature of the ambient air and that of the formed part are the same.

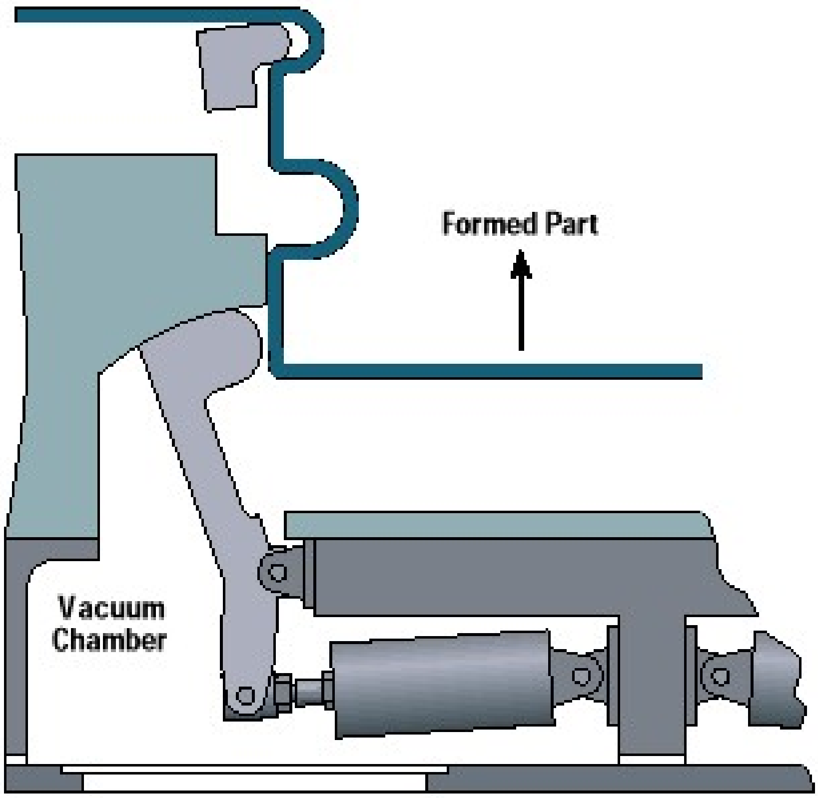
Sometimes, a part shrinks during its service life, but this is typically minimal and usually plays no significant role in the design of most parts.

Different plastics shrink at different rates. Contact GE Plastics for information by clicking on GEP Live. Part testing under actual end use conditions must be done to confirm a part's design.

Breakaways, Undercuts, and Inserts

Many thermoformed parts are produced with undercut sections. A popular method of forming a part with an undercut edge is to use a hinged undercut section.





Removable sections are often used. The operator removes the section from the formed part and returns it to the mold before the next part is formed. The undercut section can also be mechanically activated.

When a slight undercut or reverse draft is necessary, stripper plates are often used. They are either spring loaded or mechanically operated.

When a design calls for an undercut to reinforce the part, an insert is often used. Inserts, which are typically made from metal, are positioned on the mold. During the forming process, the hot sheet wraps tightly around the insert.

Sheet Selection

The thermoforming process begins with proper material selection and proper handling of the sheet before it is formed. This section of the guide contains valuable information on sheet quality, drying, and heating.

Sheet stock includes:

- Cut sheet,
- Rolled sheet,
- Extruded sheet,
- Coextruded sheet,
- Laminated sheet, and
- Foam-core sheet.

The quality specifications of the extruded sheet are established by the thermoforming processor and the extruder of the sheet. Here are some guidelines to keep in mind when trying to determine those specifications. One general note: it is best to be realistic in setting acceptable standards. Too much control can be just as costly as no control at all.

- Orientation – During extrusion, a thermoplastic resin can be stretched, causing molecules to line up more in the direction of the stretch than in other directions. The amount of shrinkage is a function of the amount of orientation. A shrinkage rate of 10 percent to 15 percent is usually acceptable (test at 350°F for one hour). Thinner sheet gauges tend to have higher orientation; thicker gauges are self-annealing and have lower orientation. High orientation can cause the sheet to pull free from the clamps during the heating cycle. Sheet orientation is almost entirely eliminated during thermoforming. As long as it does not interfere with thermoforming, orientation is relatively unimportant. Generally, the less shrinkage the better. A large amount of orientation will cause differential drawing during forming.

- Gauge Control – This should be +/- one to three percent of required thickness, based on sheet gauge. Obtaining close tolerances can be difficult, but it can provide significant benefits, including higher part output rates, less part-to-part thickness variations, and less scrap.

- Appearance – The extruded sheet should be relatively free of die lines and other surface imperfections.

- Gloss Level – Where the gloss level of finished parts is to be controlled, it should be specified as a Gardner Gloss reading number.

- Physical Property Requirements – All critical properties relating to part performance (e.g., falling-dart impact strength, tensile stress at yield and fail, elongation at fail, and modulus of elasticity) should be clearly stated. These properties can be tested on extruded sheet samples or on molded parts per ASTM test protocols. Some of these properties are affected by sheet extrusion operations, while others are inherent plastic material properties. One key property is toughness, or its ability to resist cracking when struck by another object. Toughness can affect part performance during assembly, shipment, or end use. A sheet's toughness is most commonly determined using a falling-dart impact test.

- Regrind Use – The percentage of regrind that can be used in producing sheet, as well as the condition (handling) of the regrind, should also be established. Regrind should be kept separate, clean, and uncontaminated. For example, ABS is incompatible with HIPS and PP. Contamination could cause failure. To promote sheet quality, use virgin cap.

- Sheet Storage – To maintain the quality of extruded sheet and to help ensure that it is not appreciably changed during shipping and storing, the sheet should be sealed in a heavy polyethylene wrapping. The wrapped sheet should then be securely fastened to a pallet to help prevent damage and moisture pick-up. Sheet that is to be used in applications where the appearance of the part is extremely critical should be layered with polyethylene or a soft paper before wrapping. This will help prevent scratches and will also further decrease moisture absorption. Plastic sheet can develop a static charge that can attract dust, so care should be taken to keep the sheet clean. Parts formed from dusty or dirty sheet are more likely to have surface defects.

- Moisture Content and Contamination – Moisture in and on the sheet, as well as surface contamination, are frequent causes for problems during thermoforming. Engineering thermoplastics are hygroscopic, meaning that moisture is absorbed into the sheet. High moisture content in sheet can cause surface defects during forming. It can also result in localized thinning in deep-draw parts. To reduce moisture pick-up, wrap the sheet stock (see Sheet Storage, above). In many cases, problems caused by moisture or contamination affect only the top and bottom sheets of a stack of sheet. Sometimes, smooth monolayer sheets can still be used with good results simply turning them over and using the unexposed side. This is especially true for ABS sheet. CAUTION! Don't do this for polycarbonate, PC/PBT, or sheet made from high-performance resins. Proper drying and heating of engineering thermoplastic sheet are also essential for successful thermoforming. See Drying the Sheet and Heating the Sheet for some points to keep in mind.

Drying the Sheet

Again, engineering thermoplastic resins are hygroscopic. In other words, they absorb moisture when exposed to ambient air. Failure to properly dry the sheet prior to heating can result in processing problems and can severely compromise part quality. High moisture levels can also result in:

- Decreased viscosity,
- Reduced melt strength,
- Poor process control,
- Degradation of physical properties, and
- The formation of bubbles in the sheet.

Predrying the sheet before forming will help prevent these problems. It will also help shorten the heating cycle and give more even heating, especially on heavier gauge sheet.

Sheet Thickness (in.)	Drying Times (at temperature)
0.040	1 hr
0.060	1.5 hr
0.080	2.5 hr
0.090	3.5 hr
0.125	6 hr
0.250	18 hr

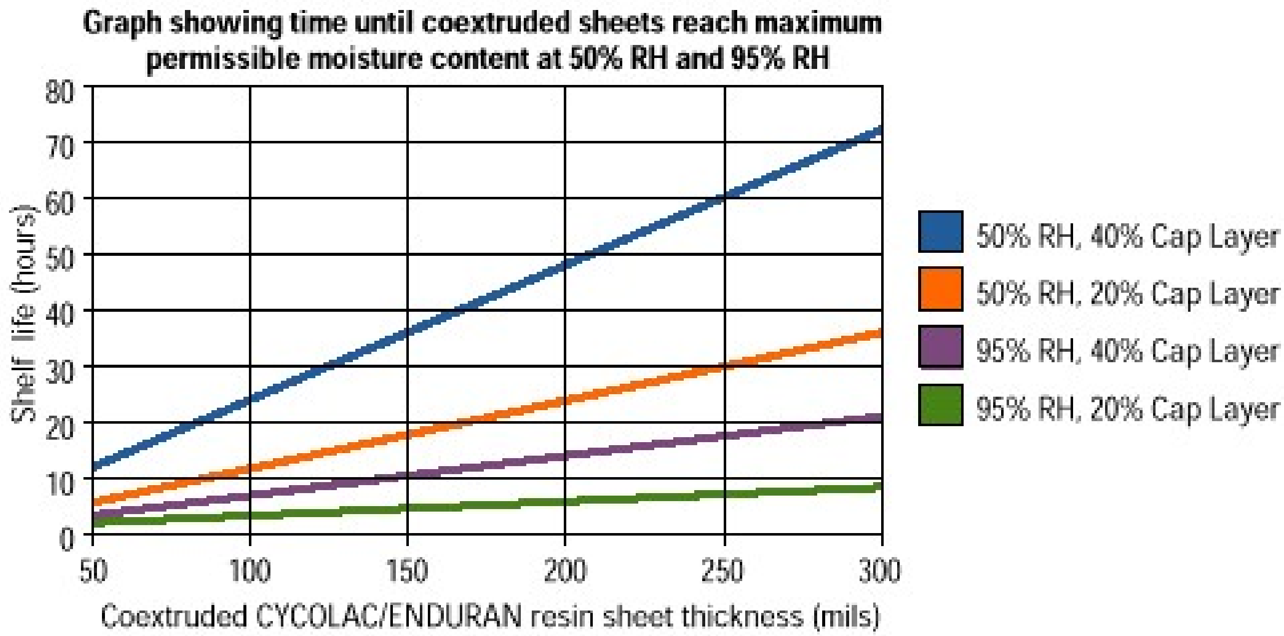
In the case of coextruded sheet, it is necessary to make note of the differences between the two materials in terms of moisture absorption. Both PBT and ABS will absorb moisture. While ABS will pick up moisture faster, it is generally more tolerant of the presence of moisture in the sheet during forming than PBT is. As an example, we'll investigate the ENDURAN/CYCOLAC system.

Permissible Moisture Levels

- Prior to sheet extrusion: 0.02 percent maximum.
- Prior to thermoforming: 0.08 percent maximum in the EUDURAN surface material layer, 0.15 percent maximum in the CYCOLAC resin layer.

As the relative humidity (RH) increases, both materials will begin to pick up moisture from the atmosphere. The difference in the rate between the two materials increases as the RH increases. However, as the PBT layer is usually significantly thinner than the ABS layer, it is typically the percentage of moisture in the PBT that governs the amount of time that the sheet requires to reach its maximum permissible moisture content.

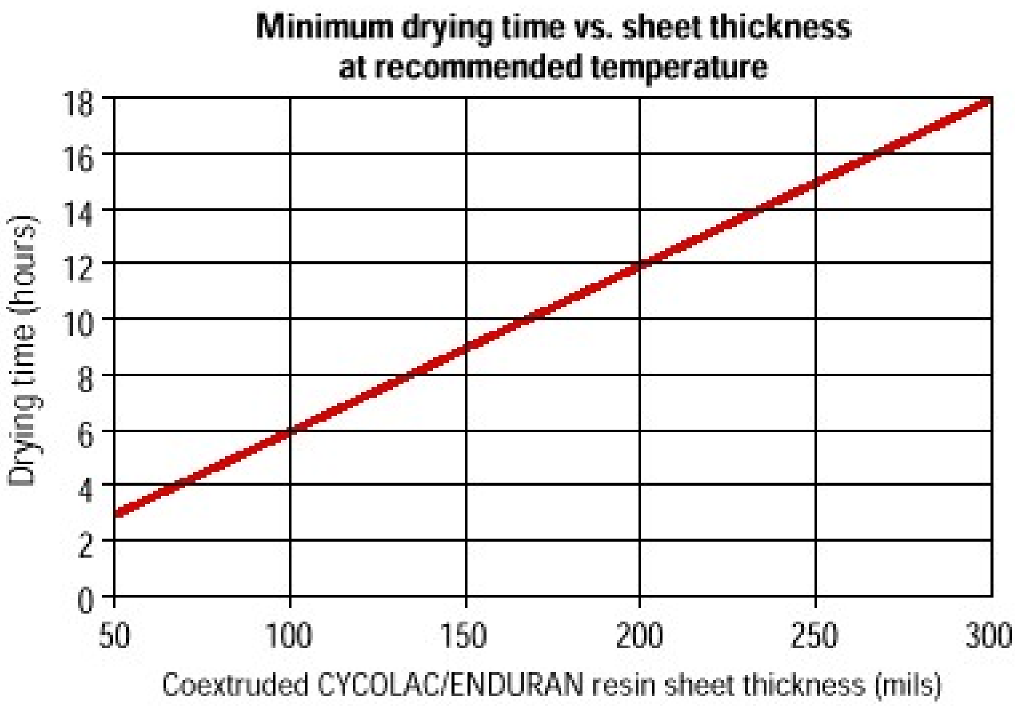
Predried sheet should not be exposed to normal room humidity for more than 10 to 15 minutes. Longer exposure to ambient humidity can result in the sheet picking up moisture. This added moisture could cause bubbles to form during the thermoforming process.



Drying

Drying times are based upon the minimum time typically necessary to dry the sheet to a thermoformable condition from complete saturation. Complete saturation is achieved when the material will no longer absorb any moisture.

Dry sheet should be used immediately or stored in a humidity-controlled environment to avoid reabsorbing moisture. If you have any doubt as to the probable moisture levels in the sheet, you should dry the sheet in an oven for the minimum time specified for the thickness.



Heating the Sheet

The resin products in GE Plastics' broad portfolio show good hot-tear strength and hot elongation properties. A gradual softening point allows:

- A wider range of operating temperatures, and
- Better process control.

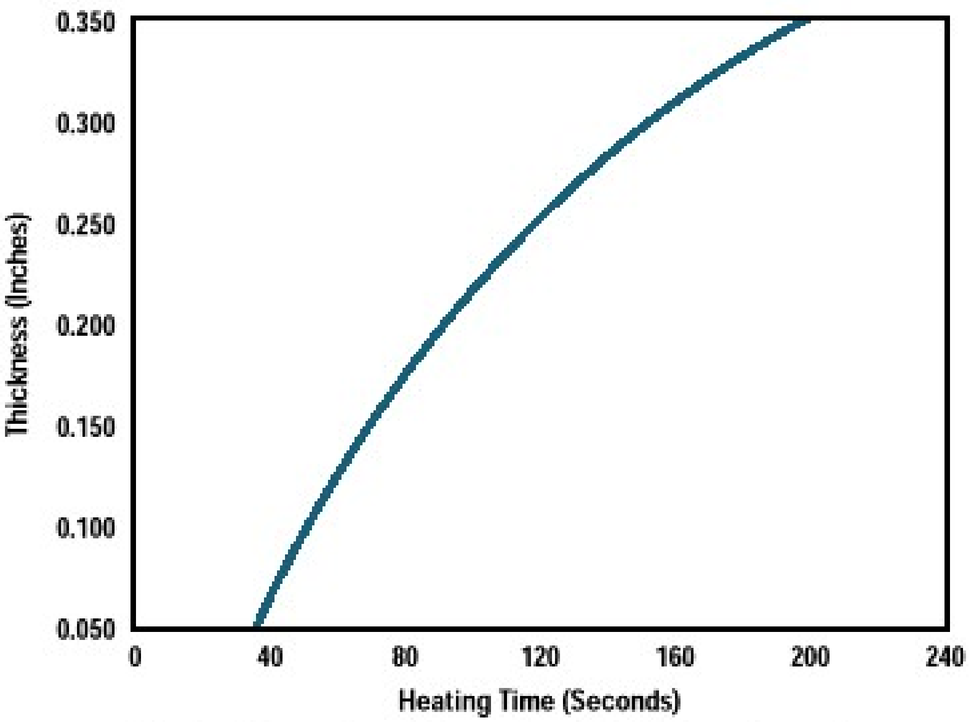
Uniform and precise control of sheet temperatures is critical to the successful thermoforming of sheet made from GE engineering thermoplastics. Sometimes, higher perimeter heating of the sheet can help the material to stretch and form. To achieve this, adjust the heating zones in a ceramic oven. For other types of ovens, wire screens are often used.

In most thermoforming operations, the initial forming temperature set-up for an application depends upon a combination of:

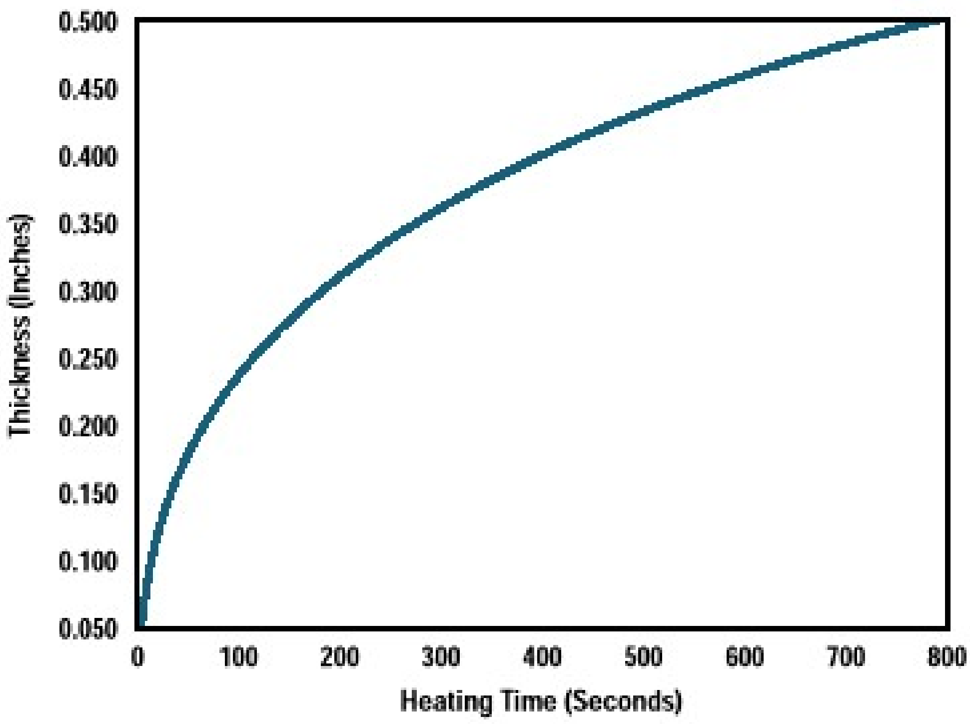
1 Measuring the sheet temperature (usually with a non contact infrared temperature sensor), and

2 Determining the correct sag of the sheet within the oven.

When it is heated, the sheet will distort, dimple, and sag. Sheet materials sag in different ways. For example, the sag of a coextruded sheet made from ENDURAN surface material and CYCOLAC resin is usually quite large and more comparable to ABS than to acrylic.



Typical heating times for LEXAN polycarbonate sheet using a commercial sandwich-type heater.



Typical heating times for CYCOLAC ABS sheet using a commercial sandwich-type heater..

At appropriate forming conditions, the sheet should exhibit very uniform sag without the presence of ripples around the perimeter of the sheet.

Formed sheet typically sets quickly and cycle times are quick.

Prior to thermoforming, the sheet must be thoroughly heated to its proper forming temperature. Heating must occur from the sheet's surface to its core and also from the center of the sheet to the edges. The recommended sheet temperatures for forming GE Plastics engineering material can be found in the Processing Temperature Table. See Table 2 for Guideline Temperatures (°F) for Thermoforming GE Resins.

It is important to note that each application is unique, and there will also be variances in sheet thickness and process machinery. Because of this, exact temperature profiles cannot be given. However, the above process temperature guide should provide a useful starting point.

It is recommended that the sheet be heated using both top and bottom ovens to enhance temperature control. Ceramic or quartz heaters have shown reliable performance because of the ease of temperature control and zoning. Where Calrod or Nichrome wire-type heating elements are used, mesh screens may be required to zone the heat.

Both thin film and heavy sheet should generally be heated 20°F to 50°F (11°C to 28°C) higher than the surface temperature required for the forming process.

Area heating distributes different temperatures across different areas of the sheet. It can be used to help control part thickness or wall thickness distribution during part formation.

The thermoforming process begins with sheet or film. Controlled heat allows the plastic to become flexible and stretched, but the sheet is not heated to the point where it would lose strength. To do this effectively and to produce quality parts, many types of equipment are used. The equipment list includes:

- Drying ovens,
- Thermoforming ovens,
- Clamping units,
- Vacuum and air-pressure devices,
- Heating and timing controls, and

- Equipment for secondary operations (trimming and post-finishing).

Drying Ovens

Engineering thermoplastics have a tendency to absorb moisture. Therefore, properly dried sheet is essential when thermoforming GE engineering materials.

Improperly dried sheet can severely compromise finished-part quality!

Ideally, sheet that is not immediately formed should be stored under a controlled temperature of 60°F to 80°F (15°C to 25°C), and in low humidity. Sheet stored for any length of time usually has to be predried before forming (see Drying the Sheet).

To dry sheet, a hot-air recirculating oven should be used. The oven should be equipped with a horizontal or compound airflow. Drying time can be lowered by equipping the oven with a dehumidifying unit to reduce the dew point inside the oven to at least -20°F (-29°C). This also helps the sheets to stay dry at lower temperatures.

All packaging materials must be removed from the coextruded sheets prior to placing in the oven. Preferably, sheets should be hung vertically in the oven or stacked horizontally, with at least a one-inch gap between each sheet to allow for air circulation.

If this cannot be done, the sheets can be left stacked on the pallet, without packaging. However, this may require a longer drying time. Stacking the sheet in the oven without using racks can result in inadequate drying of the sheets in the center of the stack. Properly designed racks can help prevent excessive sheet warpage if the oven overheats.

A hot-air recirculating air oven that can maintain a temperature of 250°F (120°C) within +/-10°F (+/-5°C) is usually adequate for drying LEXAN polycarbonate sheet. The thickness of the sheet and the rate of use will determine the size and capacity of the oven. It is generally best to maintain airflow in the oven of about 200 ft./min. (60m/min.). This airflow rate will help maintain temperature uniformity.

For CYCOLAC ABS resin and CYCOLOY PC/ABS sheet, a dehumidifying desiccant drying oven is used. The oven should be able to maintain a temperature of 180°F to 200°F (80°C to 95°C) for two to four hours. If overnight drying is required, the desiccant oven should be able to hold a temperature of 160°F to 180°F (70°C to 80°C).

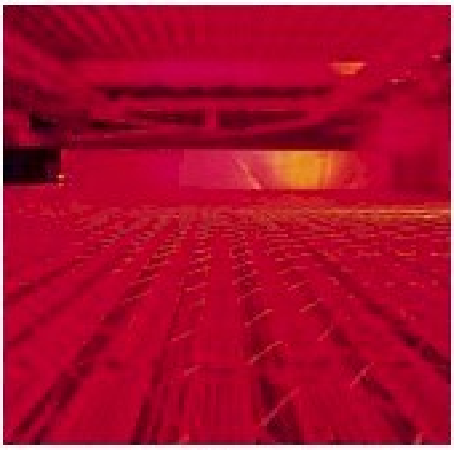
Different sheet-drying equipment is used when thermoforming roll-fed film or thin sheet. The thinness of the material permits relatively easy predrying: the film web is fed into a drying station, then continues on to the heating and forming stations.

Drying a coextruded sheet in an oven at GE Plastics' Polymer Processing Development Center.

Thermoforming Ovens

Ovens are used to heat the sheet until it is soft and pliable enough so that forming can take place. Ovens should be designed to provide even heat distribution, and each heating element should have separate controls. Screens are often used to shadow and cool localized areas and provide improved material thickness in deep-draw areas.

Convection ovens are often used, particularly for thick sheet and where free-forming techniques are used. Gas flames or electric resistance units can be used to supply heat.



Ceramic heating element.

Gas-fired infrared heaters use a gas-air mix and are available in a variety of models, each with different efficiency, reliability, and cost.

The type of heating element used in an oven depends upon the thickness of the sheet or film to be heated. “Sandwich” heater banks are notably efficient in maintaining uniform heating of the sheet.

Sheet should be kept three to 12 inches (75mm to 305mm) from the top of the heater and 12 to 18 inches from the bottom. Testing can help determine the correct top-bottom distances, which will depend on the oven’s optimum heating cycle time.

Heaters with too much capacity can cause excess sheet sagging and in some cases can even set the sheet on fire. Fire can also occur when sheets are placed too close to the heating element.

Therefore, it is important for safety reasons to always heat material properly using appropriate temperatures.

As stated above, thermoforming ovens should have separate controls for each heater, as opposed to simple off-on switches. This will allow much more process control. Temperature recorders can be used for even greater process control. To help reduce the risk of fire, thermocouple-type limit controls are often employed.

Ovens should be shielded from air currents and drafts, which can cause variations in heating temperature and affect part quality. Shields should be placed at the entrance and exit ends of the oven.

Ovens should be able to produce and maintain a temperature between 1000°F (540°C) and 1200°F (650°C). The sheet can be moved through the oven suspended vertically on trolley tracks, or it can be placed horizontally inside of trays. The trays should be insulated.

Manufacturers of Drying Ovens

Information on dryers is available through following companies:

Baker Furnace, Inc.
1015 Discovery Lane
Anaheim, CA 92801
Tel: 714-491-9293
Fax: 714-491-8221
E-mail: bakerfur@primenet.com
Web address: www.bakerfurnace.com

George Koch Sons, Inc.
10 S. 11th Ave.
Evansville, IN 47744
Tel: 812-465-9600
Fax: 812-465-9724
E-mail: sales@kochg.com
Web address: www.kochg.com

Consolidated Engineering Company
2871 McCollum Parkway NW
Kennesaw, GA 30144
Tel: 770-422-5100
Fax: 770-422-6968
Web address: www.thomasregister.com/olc/cec

The Grieve Corporation
500 Hart Rd.
Round Lake, IL 60073
Tel: 847-546-8225
Fax: 847-546-9210

Engineered Production Systems
1914 W. Orangewood Ave.
Suite 203
Orange, CA 92868
Tel: 714-939-1965
Fax: 714-939-1968
E-mail: epscrp@aol.com
Web address: www.epsovens.com

Gruenberg Oven Company, Inc.
2121 Reach Rd., P.O. Box 3246
Williamsport, PA 17701
Tel: 717-326-1755
Fax: 717-326-7304
E-mail: gsales@lunaire.com
Web address: www.gruenberg.com

Gehnrich Oven Sales Company
50 Haynes Court
Ronkonkoma, NY 11779
Tel: 516-585-8787
Fax: 516-585-9285
Fax: 714-939-1968
E-mail: gehnrich@aol.com
Web address: www.gehnrich.thomasregister.com

Precision Quincy
1625 N. Lake Shore Dr.
Woodstock, IL 60098
Tel: 815-338-2675
Fax: 815-338-2960
E-mail: pqsales@pq-corp.com
Web address: www.pq-corp.com

Wisconsin Oven Corporation
2675 Main St., P.O. Box 873
East Troy, WI 53120
Tel: 414-642-3938
Fax: 414-363-4018
E-mail: jeffkent@email.msn.com

Mold Temperature Control Factors

Mold temperatures can greatly affect part quality. Hotter molds produce greater part shrinkage. Cooler molds produce more molded-in stress.

Methods for controlling mold temperatures will depend on the type of mold in question. Prototype tooling typically employs radiant preheating. Production molds usually include machined-in channeling or cast-in tubing. These passageways circulate a temperature-controlled liquid. In localized mold heating, cartridge-type electric heaters are often used to achieve more control over material distribution in the finished part.

Vacuum, Pressure & Clamping Considerations

Using Vacuum

In vacuum forming, key considerations include the amount of air to be removed and the force available after forming the part. The larger the part, the greater volume of air that needs to be evacuated.

Good vacuum capability can be provided in a number of ways such as reciprocating pistons, sliding-vane rotaries, rotor pumps, and diaphragms. However, these generally are not efficient in removing large volumes of air quickly. When large amounts of air must be evacuated, an air accumulator located near the molds is often used.

Using Air Pressure

Pressure forming uses compressed air, which is stored in a supply tank comparable to the one used for vacuum forming. Valves and gauges should be installed next to the mold. Also, baffles placed at the mold entrance can help prevent cold air from blowing directly onto the heated sheet.

Clamping Considerations

Prior to heating, forming, and trimming, the sheet must be clamped securely between a set of frames. Clamps are usually made from iron. The iron frames should have a nonslip, gripping surface. Clamping frames must be strong and able to withstand considerable pressure. The frame should be adjusted to minimize the blank size when required.

Sheet-Fed Thermoforming Machines

For sheet that is 0.030 inches to 0.500 inches thick (0.760mm to 12.70mm), cut-sheet or sheet-fed thermoforming machines are generally used. These include:

- Single-station thermoformers,
- Shuttle thermoformers, and
- Rotary thermoformers.

Single-Station Thermoforming Machine

This is the simplest set-up for forming sheet into finished parts. Clamping, heating, forming, cooling, and unloading of the sheet are done in one location. Heaters are positioned under or over the sheet, and sometimes they are placed both over and under.

Usually, the mold is raised, and a plug is often lowered into the sheet mechanically. At that point, a vacuum is introduced (female tool) or pressure is applied (male tool) to form the part. After forming, the part is cooled while it is still attached to the mold. After the part cools, the mold is retracted and the part is unloaded.

Thermoforming using a single-station machine.

Shuttle Thermoforming Machine

Here, the sheet is clamped into a moveable frame. The frame is located to the side of the stationary heaters. The sheet is then moved into the heater; when it reaches forming temperature, the sheet is moved back to the loading station and pressed into contact with the mold. The part is formed and cooled. The part is ejected after the mold is retracted.

Shuttle-forming machines can double production and also conserve heating energy. They do this by using a second mold, an additional forming station, and two clamping frames. While one sheet is being heated, the other is being formed. Only one set of heaters is used, reducing heating costs.

Thermoforming using a shuttle thermoformer.

Rotary Thermoforming Machine

Rotary thermoforming equipment can introduce even greater productivity in forming operations by arranging three or four workstations around a central area. Rotary machines with five stations are sometimes used but are fa
common than three- and four-station machines. Only one mold and one forming station are needed on a rota

machine. Three or four clamping frames (depending on the number of workstations) are mounted on a horizontal wheel. The wheel then rotates the framed sheet from one station to the next.

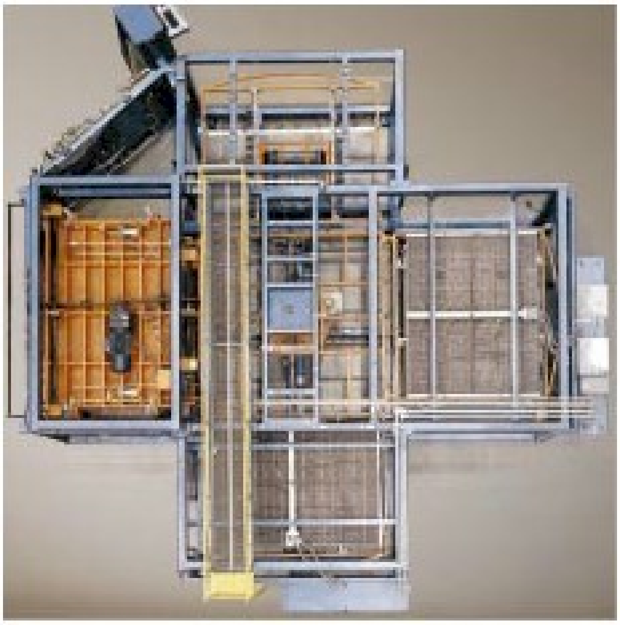
Here's what typically happens on a rotary thermoforming machine:

- First station: Opens the frame, removes the part, and inserts a new sheet.
- Second station: Heats the plastic.
- Third station: Forms and cools the part.
- Fourth station: Usually employed for robotic trimming
- Fifth station: Used for unloading operations or cooling.

Rotary machines are often selected for high production volumes and for parts that feature more complicated designs. Productivity is greatly increased because there are two, three, or four sheets being processed at the same time.

Rotary machines with two heating stations divide the heating load between two separate sets of heaters. With this set-up, dual-heater thermoforming machines are limited by cooling time rather than heating time. Output is limited by the time it takes for a part to cool after forming and before unloading.

In most rotary thermoforming machines, trimming is not considered to be part of the operation. However, some rotary thermoforming machines are manufactured with built-in trimmers.



Layout of a rotary thermoforming machine at GE Plastics' Polymer Processing Development Center (overhead view).

Continuous-Fed Thermoforming Machines

Continuous thermoforming machines are good candidates for parts with high production runs. These machines use a continuous roll of plastic film. The functions on a continuous machine are stationary and take place simultaneously.

The film moves on a line to and from each station at preset intervals. Because heating takes up the most time compared to the other operations, the film is conveyed through a heating tunnel containing multiple heaters. Cooling becomes the most significant factor in the thermoforming process.

Continuous thermoforming machines are generally used for sheet less than 0.35 inches (8.90mm) thick.

Straight-line, Roll-fed Thermoforming Machine

A continuous web of material is fed from a roll and then clamped into a chain conveyor. The web moves through a bank of heaters, gets formed, and is moved out. The part is trimmed during cooling.

Drum Thermoforming Machine

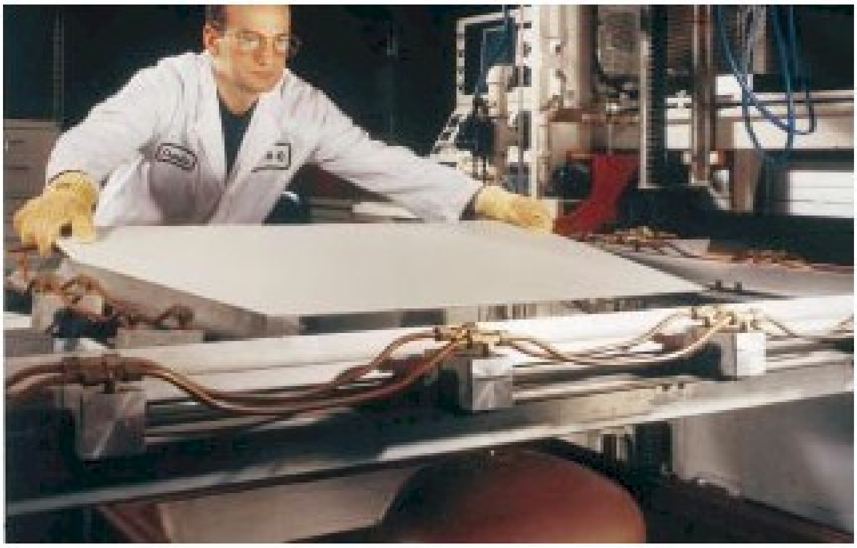
Unlike a straight-line, roll-fed machine, the web on a drum thermoformer moves onto a rotating wheel, which transports the feedstock through the heating, forming, and cooling stations. One major advantage of a drum machine is its size. A drum thermoformer has a much smaller footprint than a straight-line, roll-fed machine. Where shop floor space is limited, this can be an important benefit.

Forming the Plastic

Thermoforming is a simple process: a sheet of thermoplastic is heated and formed into a designed shape by applying heat and pressure. The sheet is stretched into a larger shape, which reduces the sheet's original thickness and results in a bigger surface area.

The sheets can be separate or part of a continuous roll.

Thermoforming starts by slowly heating the sheet so it is soft enough to be shaped. Care should be taken not to overheat the outer surface before the core reaches forming temperature. Heating too fast or overheating the surface can cause color shift, blistering, and a loss of physical properties, which can make it extremely difficult to produce quality parts.



a. The precut sheet is clamped into a frame that will carry it through the process.

Infrared heaters or gas-fired ovens are the most common heat sources used in thermoforming. The ovens are usually designed to distribute heat evenly over the entire sheet surface.

Once the sheet is pliable, it is pushed, pulled, or stretched into a female or onto a male mold so that it conforms to the shape of the mold. The finished part is then cooled so that the plastic maintains the new shape.

Pressure is applied by introducing a vacuum, compressed air, or plugs, tools, or matched molds. Vacuum ranges ypically are from 20 to 27 inches of mercury. Air pressure can range from near zero to as high as several hu psi.

All the different forming techniques have one thing in common: they force hot sheet over or into a mold.

b. After heating in an oven to forming temperature, the sheet is moved into position above the tool.

Forming begins by sealing the clamped, preheated sheet into the mold. Prestretching, if required, can be achieved by introducing a partial vacuum, air pressure, or by using a plug assist.

While the sheet is within the proper forming temperature range, air pressure or vacuum is applied. This forms the sheet:

- Onto the mold for a male mold,
- Into the mold for a female mold, or
- By having matching male and female molds combine to force the sheet into the new shape.

c. Here, the newly formed part is seen cooling on the mold.

The formed sheet is held in place to cool. When the finished part has cooled down enough to hold the new shape, it is removed from the mold. The same process is then repeated to form the next sheet.

d. Once cooled, the finished part is removed from the clamp frame and the mold.

Two Methods, Many Options

There are two methods of thermoforming:

- Basic thermoforming – Forms the heated sheet in one operation. There are many basic forming methods:
- Straight Vacuum Forming,
- Drape Forming,
- Pressure Forming,
- Free Draw (with vacuum or pressure), and
- Matched-mold Forming.
- Advanced thermoforming – Here, the heated sheet is prestretched prior to forming. Advanced forming methods include:
- Plug-assist Forming (both Vacuum and Pressure),
- Snap-back Forming (both Vacuum and Billow),
- lip-ring Forming, and
- Twin-sheet forming.

Basic Thermoforming

Basic thermoforming forms hot, pliable sheet into the finished part in a single operation.

There are numerous factors that affect part quality, but a note about sheet temperature should be made here. Sheet temperature is difficult to accurately measure. Heat enters the sheet through the surface and penetrates into the core. This means that the surface is always hotter than the core. Therefore:

The average sheet temperature is the most important characteristic in determining the forming temperature.

The same "average" sheet temperature can be achieved under several heating conditions. For example, with high intensity heat, the surface will heat quickly, and the average temperature may be 300°F (149°C), with a relatively cool core. With lower heat and a longer cycle, the surface and core will be nearer to the same temperature.

Before the forming temperatures are established, keep a couple of things in mind

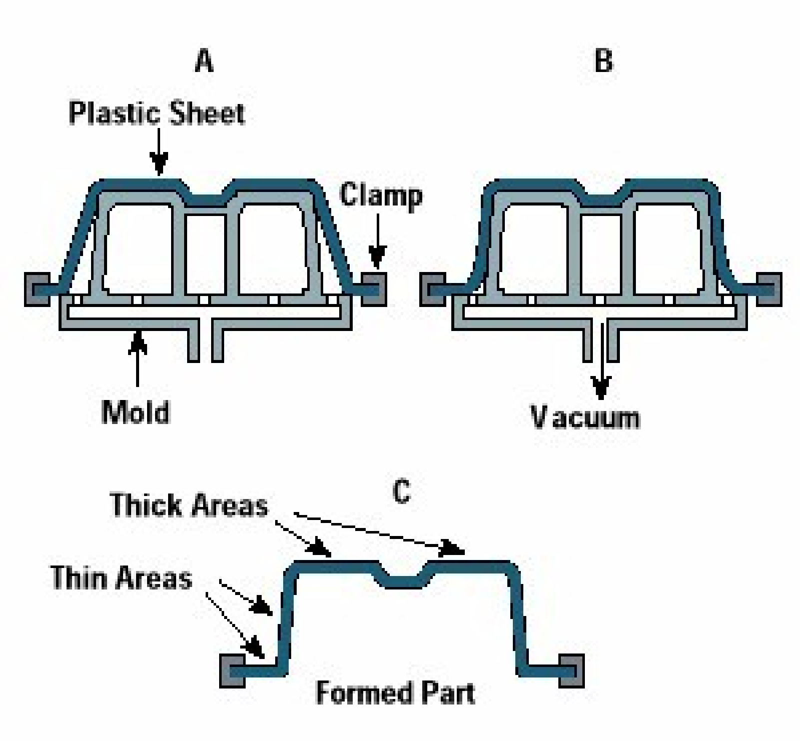
1. Forming at low temperatures generally gives the best hot strength, reduces spot thinning, and can shorten the cycle.

2. Forming at high temperatures typically lowers internal stress but also increases mold shrinkage and may affect material thickness.

Typically, a compromise between the two is used to produce parts with acceptable quality at a satisfactory cycle time.

Straight Vacuum Thermoforming

This is one of the most common thermoforming methods. A vacuum removes air between the sheet and mold and draws the sheet into a male or female tool. The vacuum is applied from underneath the sheet, pulling it into the mold.



Straight vacuum molding with a male mold.

Several factors are critical in straight vacuum forming. These include:

- Tool surface,
- Size of the vacuum holes, and
- Spacing of the vacuum holes.

Straight vacuum forming generally allows good mold reproduction and quick cycle times. The process is also used for making sturdy parts, because the wall thickness at the sheet's edge will be nearly the same as in the original, unprocessed sheet. Straight vacuum forming is also a good candidate for parts with low profiles that don't require deep draws.

Drape Thermoforming

Drape forming is another simple forming method that is used for parts with deep draws. Mold details typically reproduce well.

A vacuum removes air in the mold (male or female) as the mold closes onto the hot sheet.

Parts made by drape forming typically have several features:

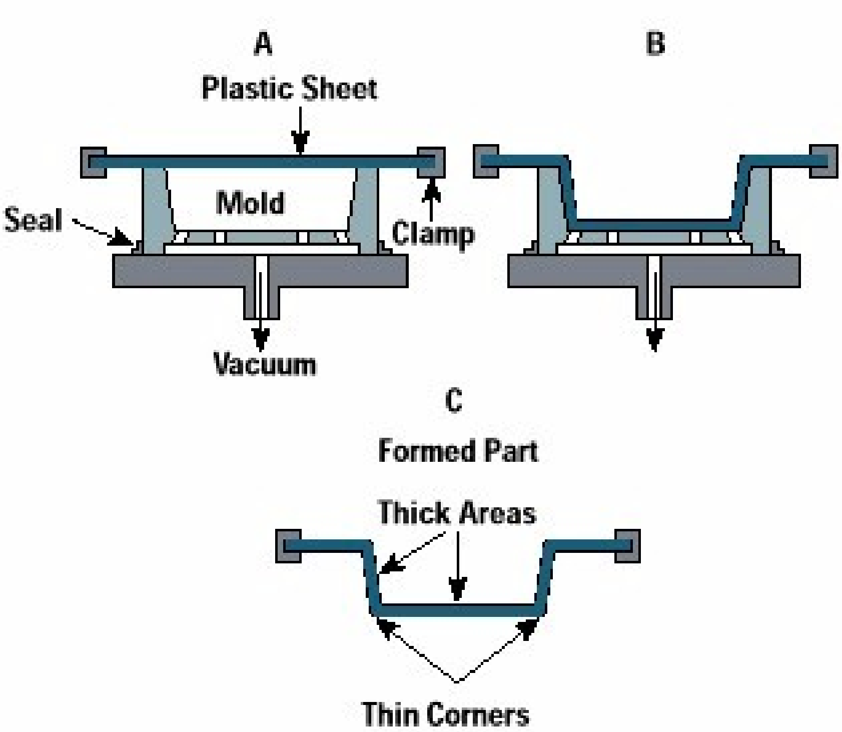
1. The sharpest details occur on the outside of the part.

2. The formed part solidifies at nearly the original thickness of the unprocessed sheet where the sheet touches the highest part of the mold.

The last area to be formed will be the thinnest and weakest area.

For Female Tools

When the sheet cools, it will pull away from the mold, generally releasing parts with vertical walls or even slight undercuts after forming.



Straight vacuum forming with a female mold.

Pressure Thermoforming

In the pressure forming process, heated sheet is forced into the tool using compressed air. The sheet makes contact with the edge of the mold, forming a seal. Air pressure is then introduced on the side of the sheet away from the mold. This pushes the sheet against the mold to form the part. Often, a vacuum is also applied to help bring the sheet into contact with the mold.

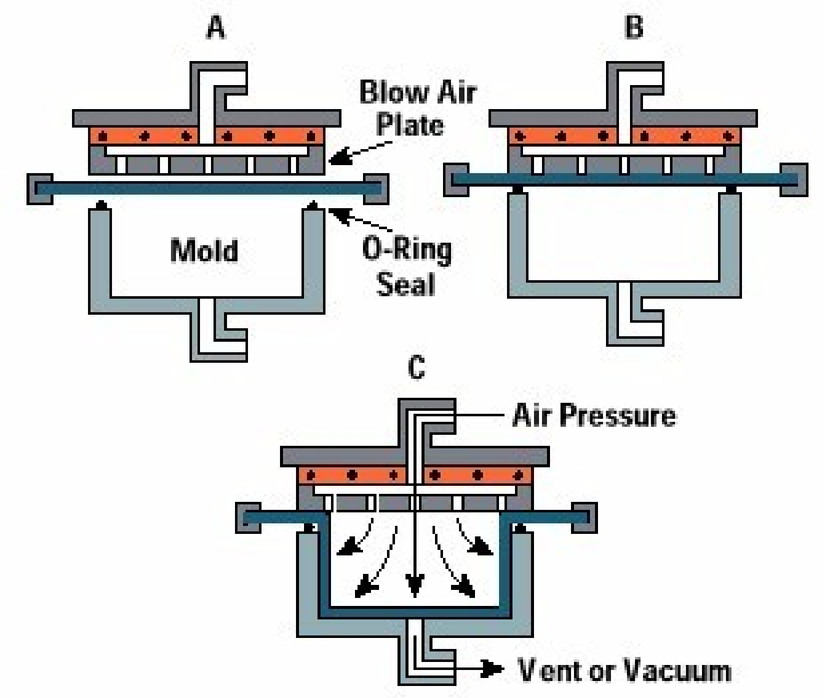
Pressure forming allows faster cycles than vacuum forming because the sheet can be formed at lower temperatures. This processing method usually has a couple of distinct advantages over vacuum forming:

- Greater reproduction of details from the mold surfaces. Sharp, crisp corners; sharp, well-defined edges; various surface textures; letter and logo reproduction, both raised and etched; and accurate location of apertures reproduce well.
- Closer contact of the sheet with the mold surface. This allows greater control over cooling, which can lead to less residual stress and faster cooling cycles.
- Greater dimensional control.

In comparing pressure thermoforming with vacuum thermoforming, one major drawback with the former is that molds are more expensive since they feature more intricate detail. Other potential disadvantages include:

- Extra reinforcing to offset the higher mold pressures, and
- Longer lead times.

Compared to injection molding, pressure forming is more cost effective in terms of tooling and parts pricing (the larger the part, the greater the savings). Lead times are also usually better in short production runs.

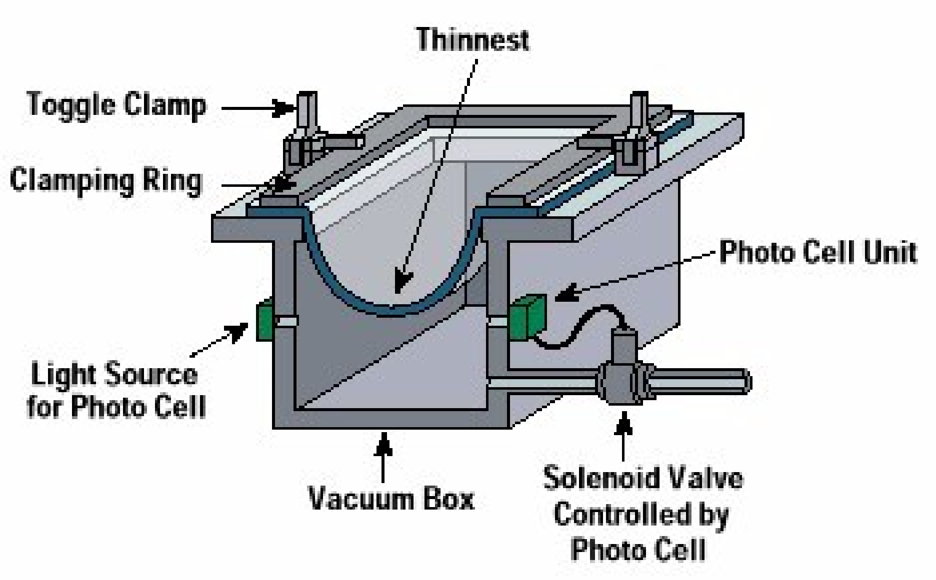


The pressure forming process.

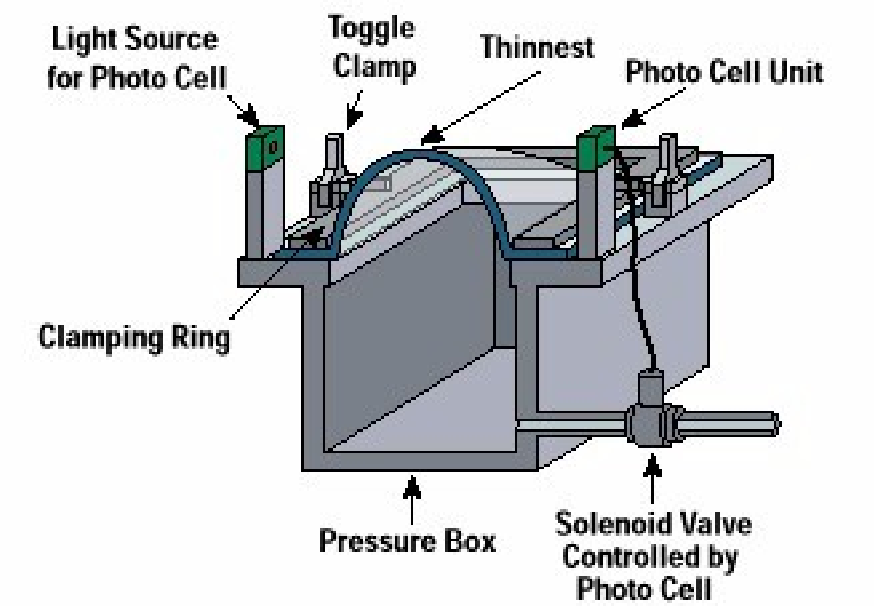
Free Draw Thermoforming

Free draw uses either vacuum or pressure to produce thermoformed parts without a mold, making it very useful for applications requiring transparency or optical performance such as skylights and windows. In fact, the portion of the sheet that doesn't touch the mold will have optics as good as the optics of the original, unprocessed sheet.

In free draw forming, heated sheet is blown into a bubble with air pressure or drawn into a cavity by means of a vacuum. The bubble is formed, then held in place by the pressure or vacuum until the part cools.



Vacuum free draw
forming.



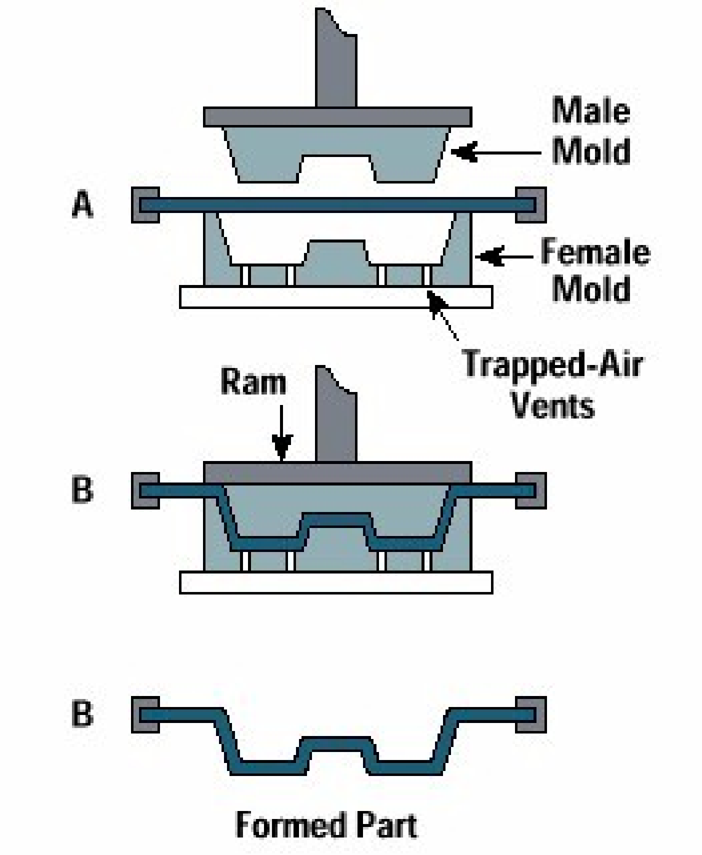
Pressure free draw forming.

Matched-Mold Thermoforming

Matched-mold forming uses two identical molds to form the heated sheet. The softened sheet is compression-molded between the molds, which are mounted on platens. When the mold halves close on the pliable sheet, the finished part is formed, with the air escaping through mold vents. Matched-mold forming is a good candidate for applications requiring reproduction of fine details from the mold, such as lettering and textures.

The use of a vacuum or air pressure is not required in matched-mold forming. Note that if the two molds are made from similarly hard materials, care must be taken to keep the molds closely aligned during forming. Usually, however, one of the molds is made from a softer material (e.g., rubber) to lessen the need for monitoring and realignment. The softer surface is not shaped exactly to the part but is used simply to force the sheet against the opposite mold face.

In the matched-mold process, the sheet is heated to a significantly lower temperature compared to conventional thermoforming. This saves heating costs, but tooling investment is higher because the process requires two molds.



Thermoforming using matched molds.

Advanced Thermoforming

Advanced thermoforming involves prestretching the sheet before it is formed. This promotes even material distribution and uniform wall thickness. Advanced methods are used for applications with deep draw ratios.

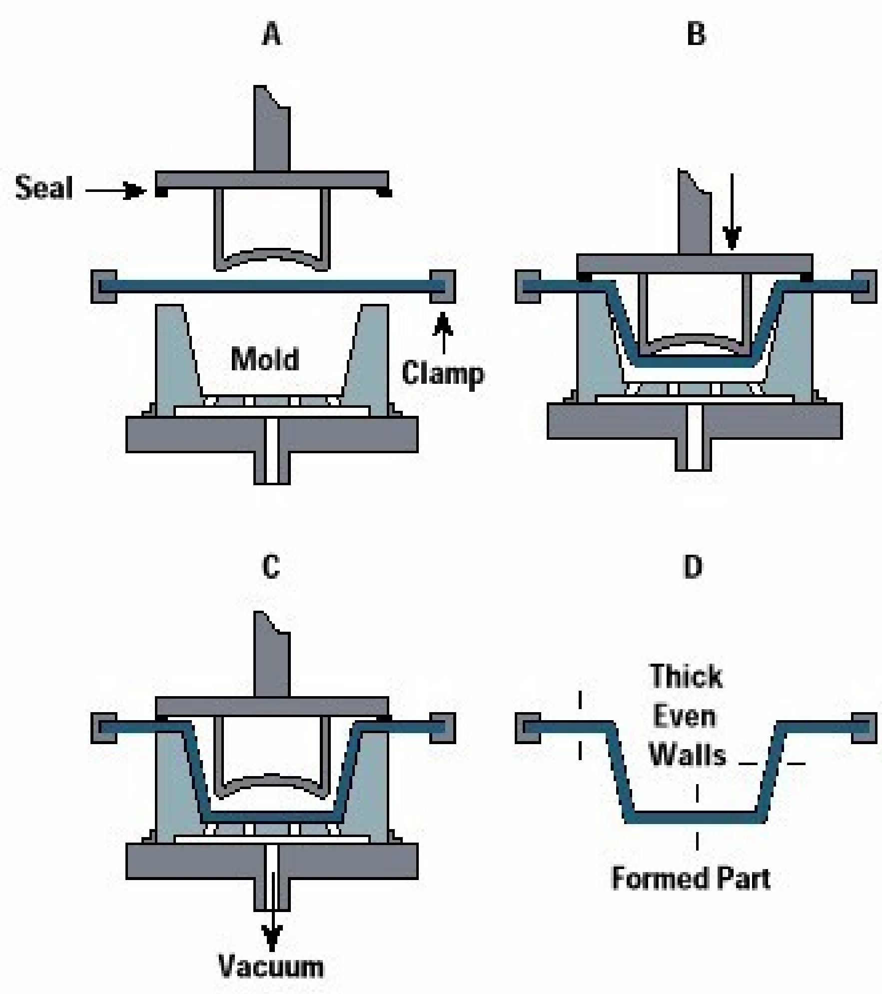
Sheet can be stretched over or into a mold by using a plug or it can be pneumatically stretched into a blister shape, then stretched mechanically.

Plug-assist Thermoforming

Plug-assist vacuum forming combines many of the best features of straight vacuum and drape forming. It can produce finished parts with good material distribution, parts that are easily removed from the mold.

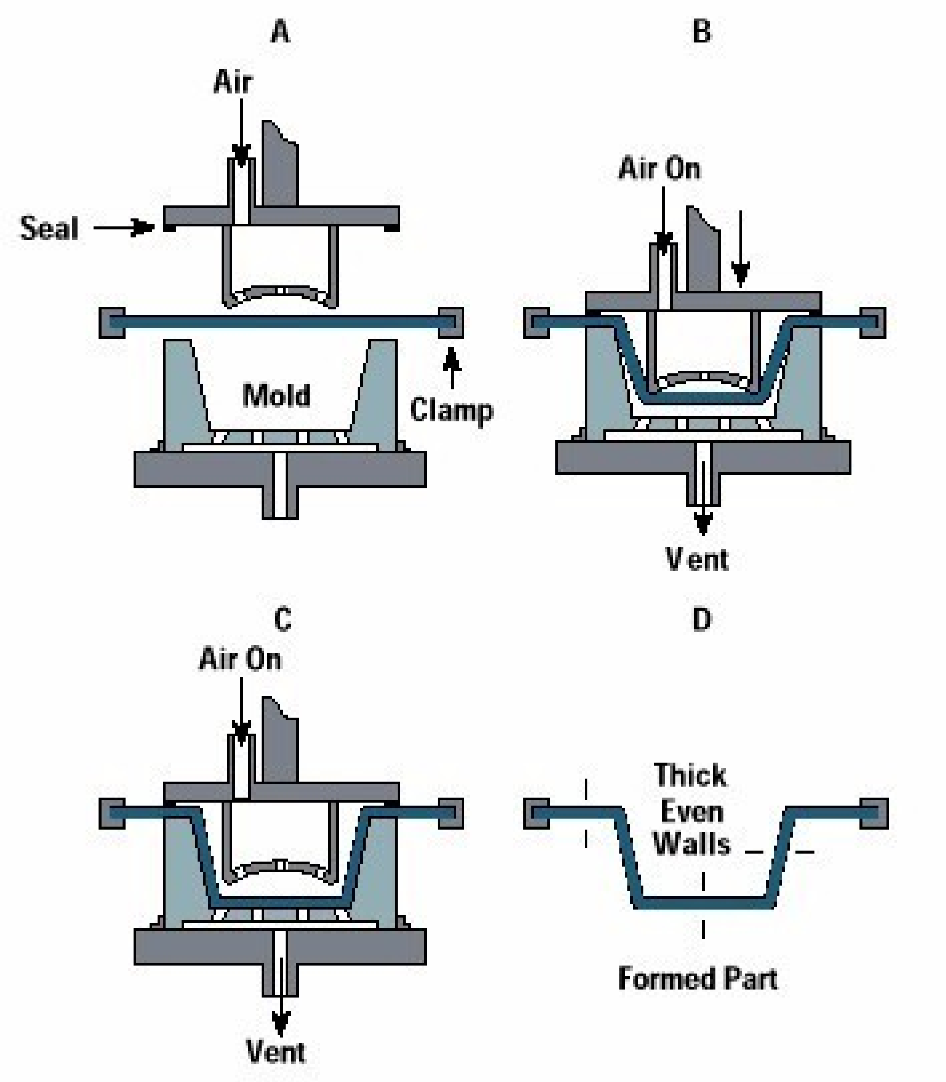
Heated sheet is clamped over a female mold. As a plug forces the sheet into the mold cavity, the air under the sheet is compressed. The sheet then “billows” up around the plug, preventing the sheet from touching the mold.

The plug actually stops near the bottom of the mold. Because the plug doesn’t touch the sides of the mold, the sheet is stretched more uniformly. A vacuum then pulls the sheet into direct contact with the mold, forming the part. The plug is then removed.



Plug-assist vacuum forming.

Plug-assist forming can also employ pressure instead of a vacuum. After the plug pushes the sheet into the mold, pressure from the plug side makes the sheet billow up around the plug. The sheet contacts the mold and the part is formed.



Plug-assist pressure forming.

Many variables affect the quality of parts produced by plug-assist thermoforming. These include:

- Seal Restriction – The area of the sheet to be sealed against the mold should be restricted to allow more process control.

- Sheet Temperature – Sheet temperature is usually a compromise in plug-assist forming. Try to keep temperatures near the middle of the forming range. Though too much heat can degrade the material, higher sheet temperatures can reduce orientation. Excessive heat can also make thinner sections toward the bottom of the mold and cause drag lines. Also, sheet can sag too much if temperatures are too high.

- Plug Design – Typically, the plug size should be about 70 percent to 90 percent of the mold volume. A good starting point is 85 percent. The plug should conform to the general contour of the cavity. Plugs are often made of conductive material such as aluminum, although other materials can be used (thermosets, foam, hardwood). Felt is sometimes used to insulate the material from the plug. The plug is often heated to avoid chilling the sheet during plug stretching.

- Plug Speed – How fast the plug penetrates the sheet can affect material distribution. Generally, processors should use the fastest plug speed. Slower plug speeds tend to cause drag lines. In general, the plug's initial speed should be about 3½ to 4½ inches (89mm to 114mm) per second. The plug should go to within 5 percent to 10 percent of the bottom of the mold. When the plug bottoms out, a vacuum and/or pressure should be applied.

- Billowing – The sheet should billow upward as the plug moves into the sheet. This is caused by the plug compressing the air in the mold faster than it can escape through vent holes. Billowing is influenced by:

- The area of the sheet clamped to the mold,
- Plug speed,
- The ratio of vent openings to the cavity volume, and
- The difference in pressure across the vent openings.

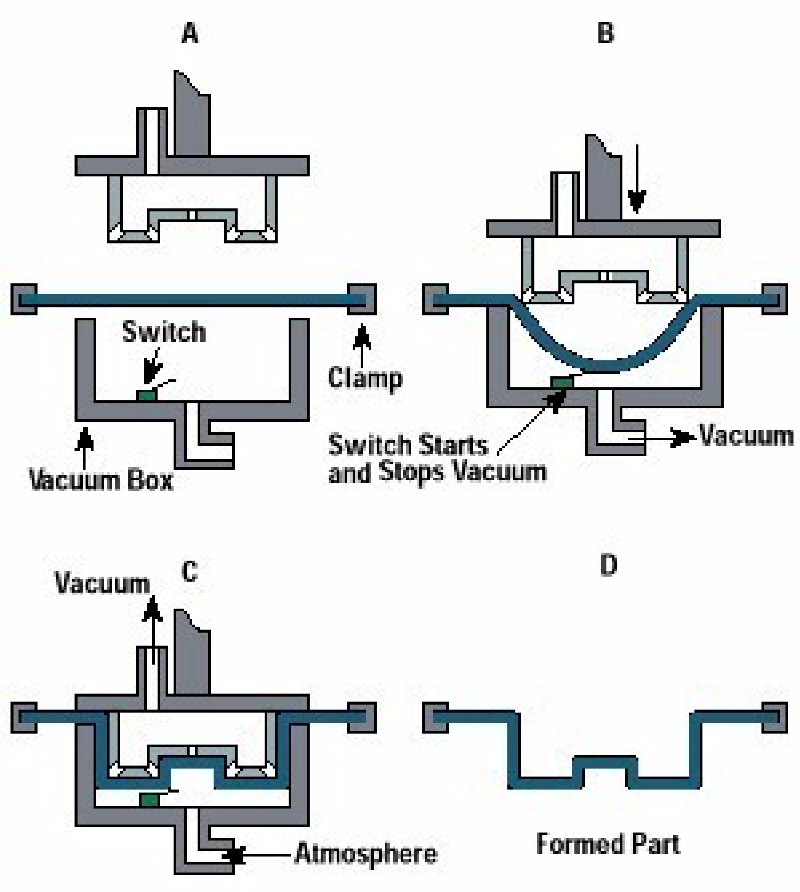
With most production molds, rapid plug penetration will probably cause the build-up of excessive pressure. If this happens, additional vent holes may be needed.

Snap-back Thermoforming

Vacuum Snap-back Forming

In the vacuum snap-back process, the heated sheet “snaps back” onto the male mold to form the finished part. The heated sheet is sealed to the vacuum box. A vacuum is applied through the box; this prestretches the sheet as the male mold seals against the box. A vacuum is then applied, causing the prestretched sheet to snap back against the male mold.

After the sheet is pushed against the mold, the vacuum box is moved away from the part. Cooling fans are then activated. As in any vacuum-forming technique, the vacuum is maintained until the part has cooled to the heat distortion temperature of the sheet.



Vacuum snap-back thermoforming.

Vacuum snap-back forming has a number of potential advantages over other forming methods in producing quality parts, including:

1 A smaller starting sheet can be used,

2 Improved material distribution,

3 Reduced chill marks,

4 More uniform wall thickness, and

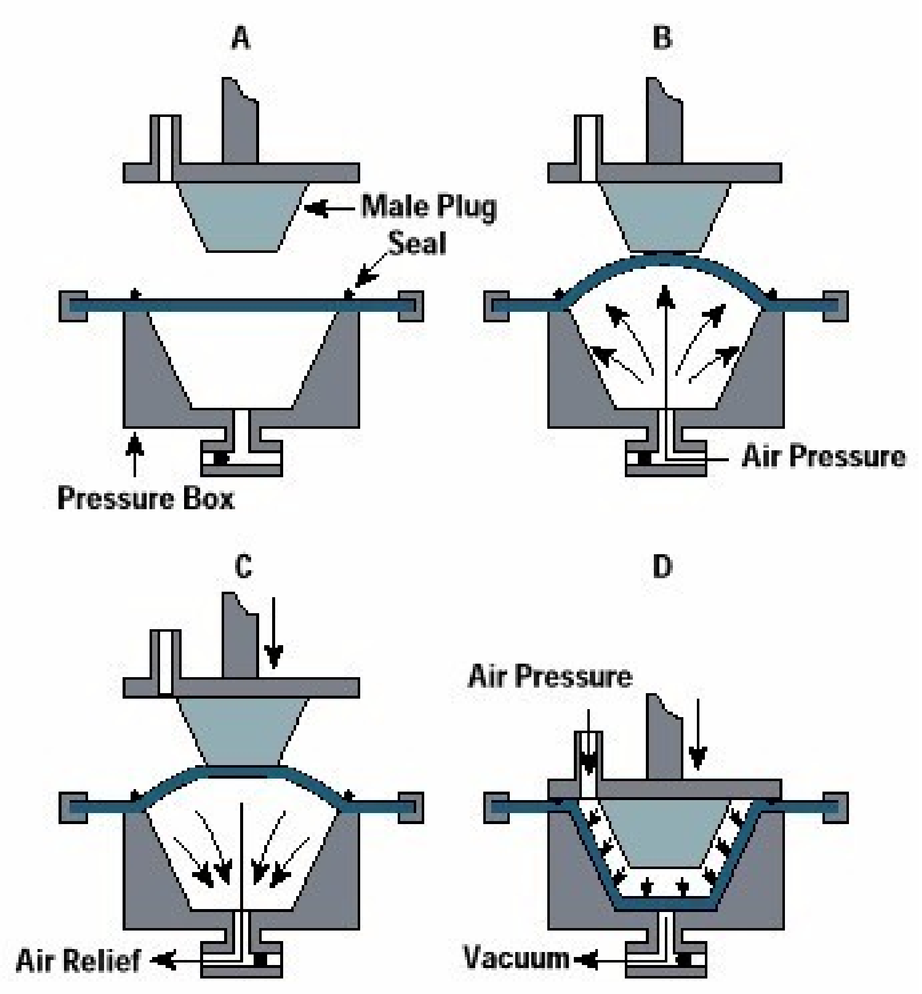
5 Better part-to-part reproducibility.

Each of the different steps in snap-back forming can be controlled with timers and limit switches. Automatic process controls will help the thermoformer achieve consistent results, and are recommended.

Billow with Plug Assist

The billow with plug assist process is often used to produce parts that require a very uniform wall thickness. Billow with plug assist forming can be done using either female or male molds.

The sheet is heated, then clamped and sealed against the pressure box. Air pressure introduced under the sheet causes the sheet to billow upward. The height of the billow is usually about 65 percent to 70 percent of the part’s depth for the first trial, and then it is adjusted as required. A plug is then inserted into the billow and a vacuum is introduced.

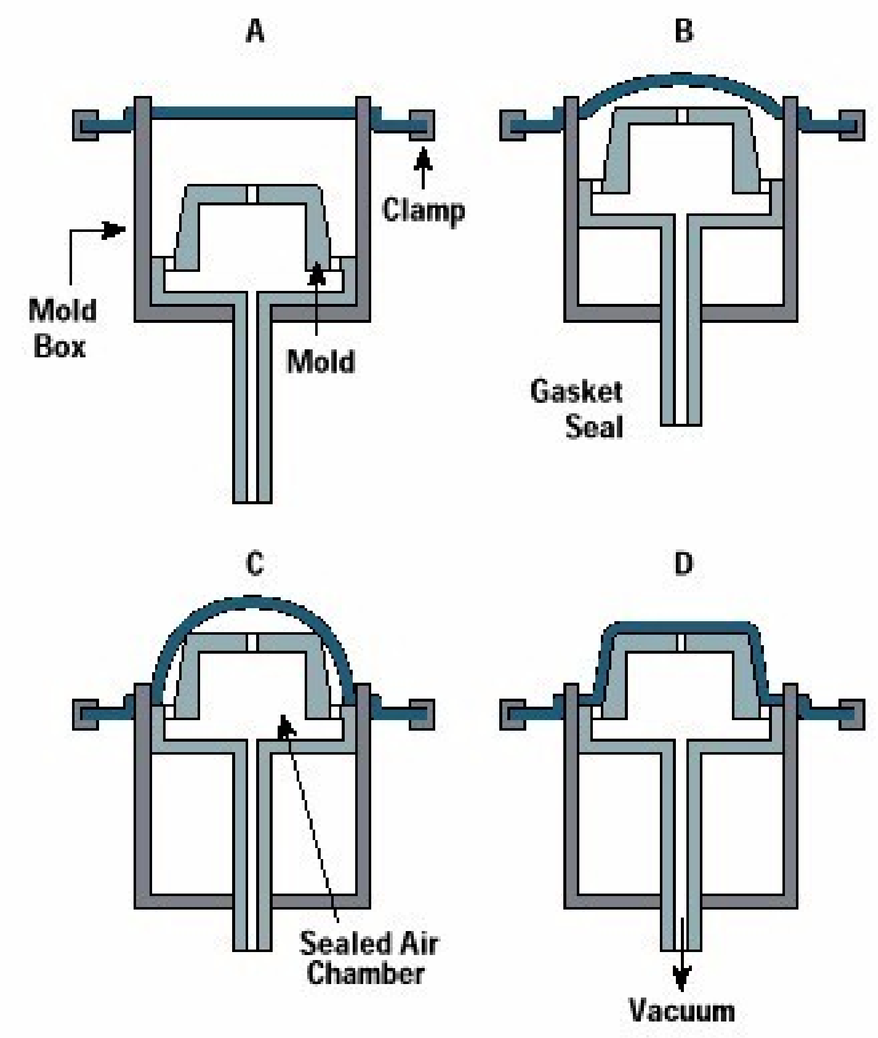


Billow with plug assist thermoforming.

Slip-ring Thermoforming

Slip-ring forming is like snap-back forming. The chief difference is that the slip-ring method uses an alternate procedure to prestretch the sheet. The heated sheet is placed on a spring-loaded slip ring. The ring is then drawn over the mold. The sheet slides through the ring in a drawing action. The ring approximates the shape of the mold base so that after drawing, no further forming is needed. Parts formed by the slip-ring method generally exhibit excellent uniformity in wall thickness.

In this production method, the sheet is not gripped as tightly as it is being formed, which can help in getting more material out of the clamping frame and into the part.



Slip-ring thermoforming.

Twin-sheet Thermoforming

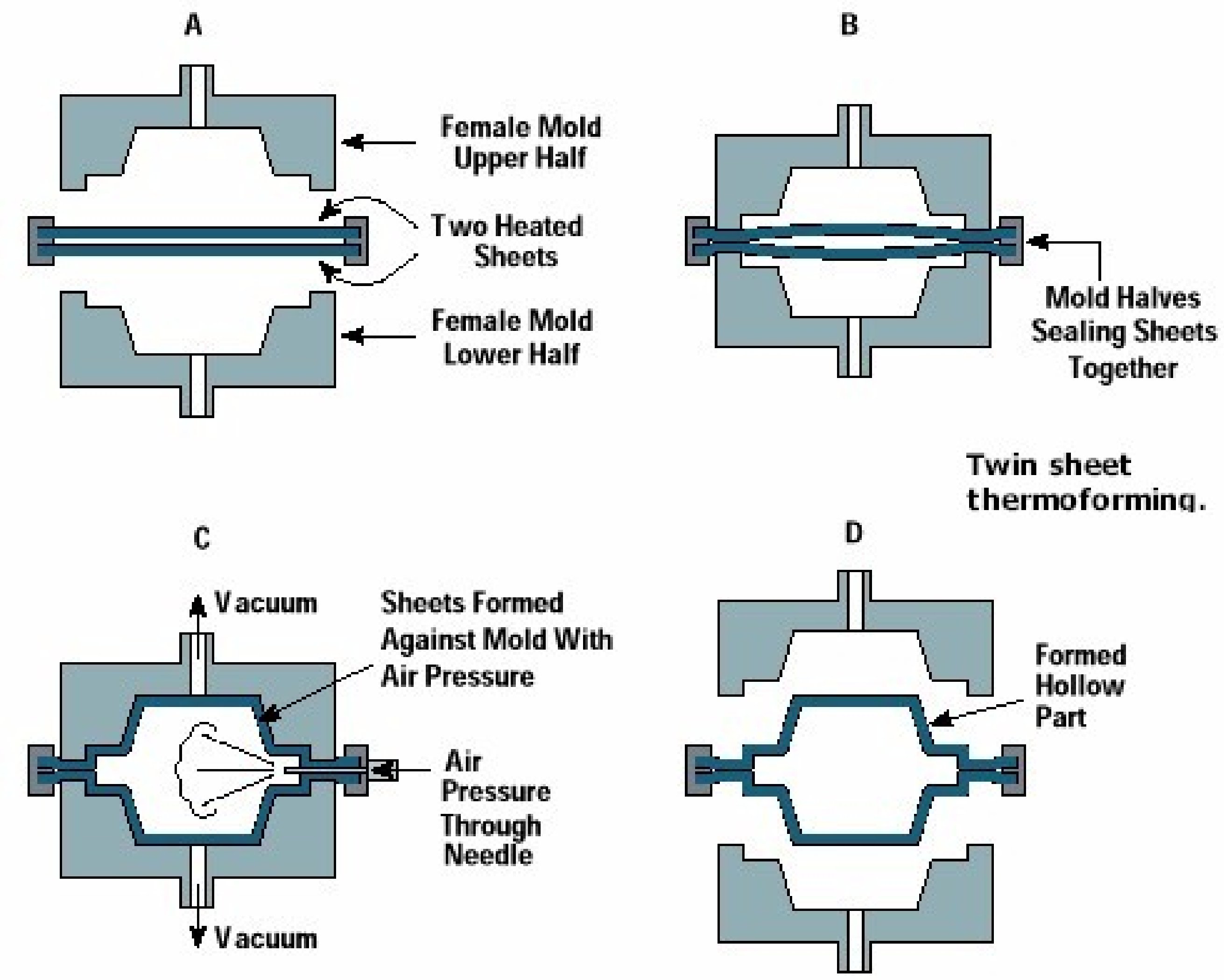
Twin-sheet forming is used primarily to produce structural parts needing great rigidity, such as pallets, containers, air plenums, and ducts. Also, twin-sheet forming is often used in forming double-walled parts.

In some applications, twin-sheet forming has become an alternative to blow molding. The process is simple. However, producing consistent parts requires tough, rugged equipment having accurate controls.

In twin-sheet forming, two sheets of plastic are heated and held in separate clamping frames. Two female molds are used. The heated sheets are inserted together between upper and lower female mold halves.

The mold halves then close, sealing the edges of the sheet. A vacuum is introduced at the same time pressurized air is blown between the two sheets, inducing the plastic to conform to the mold walls and also helping to cool the part. Applying pressure between the two sheets helps improve product definition. As the two molds open again, the formed part stays in the clamping device for removal and post-forming.

Forming can be achieved by using compressed air or by simply evacuating both mold halves simultaneously. Twin-sheet forming produces finished parts resembling those made by blow molding or rotational molding.



Removing & Cooling the Finished Part

Cooling

Before the formed part can be taken from the mold, it must be cooled. Removing the part before it has properly cooled can lead to warping or other distortions. Parts formed over male molds should be removed before thermal shrinkage occurs, or it may become difficult to remove the part from the mold.

Cooling is as important to thermoforming as heating, and care should be taken to select the cooling method that's most appropriate for the application. Keep in mind that cooling slows markedly once the part is taken from the mold. To avoid subsequent trim errors, keep the same time interval between part removal and part trimming.

Sometimes when forming heavy-gauge parts, which generally do not tolerate internal stresses very well, natural cooling is slowed by covering the part with a blanket. The clamps holding the sheet can also be loosened during cooling.

Again, the basic goal of cooling is to remove most of the heat absorbed by the sheet during the heating and forming cycle. Proper cooling will not only make it easier to remove the part form the mold but will reduce the chances of damaging the finished part.

There are only two feasible methods for cooling a thermoformed part: conduction (heat loss from the mold) and convection (heat loss to the surrounding air). The heat will not properly dissipate from radiation because the temperature of the formed sheet is too low.

- Conduction – Hollow metal rods deliver water into the mold to cool the part as it lies in the mold. Even water temperature should be maintained.

- Convection – Parts with thick walls take longer to cool. In fact, most all parts over 1/16 inches thick will require longer cooling time. This must be taken into account when determining manufacturing economies. Faster cooling can sometimes be achieved by using fans to blow air on the exposed side of the part while still in the mold.

Other cooling methods, such as spraying the part with water or liquid carbon dioxide, are untidy and expensive. Their use is not recommended.

Part Removal

If the part has been properly cooled, part removal is generally simple. The mold is opened and the part manually removed. Sometimes air can be used to help in removing parts. Mold-release agents can also be employed as an assist. Another factor in part removal is the quality of mold design.

Secondary Operations

Because thermoforming begins with a relatively expensive finished sheet of plastic, minimizing scrap is an important step in containing costs. Though good part design can reduce trim, some trimming will be necessary. The point is this: keep the amount of excess plastic that needs trimming to as little as possible. In addition to trimming, other secondary operations may be required. These include fastening, printing, and decorating.

Trimming the Formed Part

It's generally best to trim a part when it is warm. High-production parts are usually trimmed right in the mold.

Trimming parts thermoformed from engineering thermoplastics requires rugged equipment. To remove trim, scissors, knives, saws, and water jets can all be used. Punch-and-die trimming is another method of removing excess material.

Trimming should be done in a separate area designated just for that operation. Accurate positioning and holding of each part is important. Small, thin parts are usually held in place by surrounding locators. For parts with complex shapes, fixtures should be built to hold the part in place while it is being trimmed.

Generally, for greater process efficiency and economy, it is best to perform other part-finishing steps (drilling, machining, assembly) with trimming when that is possible.

Scrap Reuse – Plastic removed from the part during trimming can be ground up and later reused. However, this should only be done if the material is clean and properly dried. Regrind must come from properly molded parts or from the trim of those parts. All regrind should be thoroughly blended with virgin resin before drying and processing. Never reuse scrap that is contaminated or not properly dried. Be sure to consult with the material manufacturer regarding the use of regrind for specific materials.

Fastening the Formed Parts

There are many ways to join thermoformed parts, including:

- Mechanical fasteners,
- Press and snap fits,
- Solvent bonding,
- Adhesive bonding, and
- Ultrasonic welding.

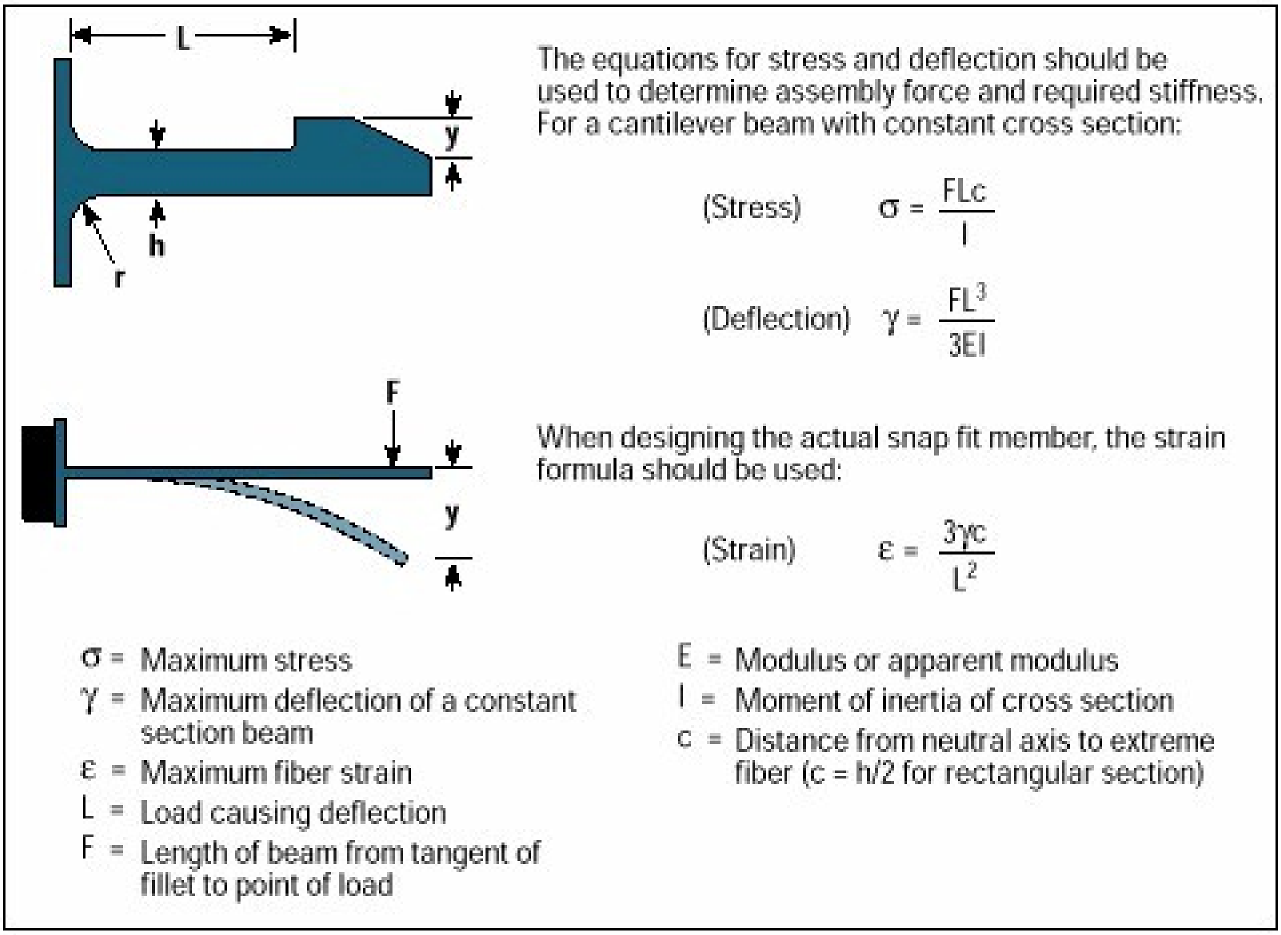
Mechanical Fasteners

In general, the best way to join thermoformed parts is to use mechanical fasteners such as screws, bolts, and rivets. Mechanical fasteners typically produce a secure and lasting joint. Also, no surface preparation is needed and no hazardous chemicals are required.

Press and Snap Fits

Most thermoformed parts can also be easily joined together by designing in press and snap fits. Snap fits use the inherent flexibility of plastic to eliminate fasteners and to secure parts in assembly.

Snap fits can be designed for either permanent (one-time) assembly or for multiple insertion and removal. Snap fits must endure large stress and strain levels, so care should be taken to design fits that can withstand nonlinear stress-strain effects. In addition, snap fits can be geometrically complex when the base radius, angle of orientation, taper, and thickness gradient vary. Often, these factors can be accounted for in a simple linear beam equation.



Snap-fit design.

Solvent Bonding

Many thermoformed parts can also be joined by using solvents. To bond parts together with solvents:

- Make sure you have a good mating surface.
- Have a means to clamp and hold the joined surfaces together.
- Allow proper drying before testing.
- Observe all safety precautions when using solvents

Adhesive Bonding

Adhesives can often be used to join thermoformed parts. Adhesive bonding materials include epoxies, urethanes, acrylics, anaerobics, and cyanoacrylics. Each type of adhesive has a unique set of characteristics. Selection of an adhesive should be based on manufacturing and end-use needs such as working time, cure time, strength, and flexibility. As with solvent bonding, be sure to have a good mating surface and allow for proper drying.

Following is a description of each of the five major types of acrylics. For a comparative look at Adhesives, see Table-3

- Epoxies – Extremely versatile, these adhesives are structural and provide a high level of gap filling. Their bond strength, electrical conductivity, and temperature resistance can be modified to fit most applications. Epoxies are packaged in one- or two-part systems. One-part systems are easier to handle, but they must be cured at elevated temperatures (typically 300°F [149°C]) for one hour. Most one-part systems have great strength. However, the shelf life is limited compared to two-part systems. Two-part systems have the added advantage of room-temperature curing capability. Epoxies are not solvent-based. They cure as a result of a chemical reaction

- Urethanes – Often called polyurethanes, these adhesives provide strong bonds on a variety of substrates. Urethanes are often used in applications that require flexibility and when two substrates have different coefficients of thermal expansion. Like epoxies, urethanes are typically structured adhesives, provide gap filling, and come in one- and two-part systems. Hot-melt systems are usually polyurethane-based.

- Acrylics – Acrylics have some of the strength and gap-filling advantages of epoxies and urethane, while adding another benefit: they rarely need primers. Acrylics have a relatively rapid cure rate at room temperature. Heat can be used to further reduce the cure time. Methacrylics are a subset of the acrylic family.

- Anaerobics – Anaerobics are a one-part thermosetting adhesive family whose curing mechanism is triggered by the absence of oxygen. The cure only begins when the two materials are mated together. This eliminates the problem of premature curing. Curing occurs at room temperature and can be accelerated by heat or ultraviolet radiation. These adhesives can usually be easily cleaned from the unbonded surface after the bonding has set up. Anaerobics are especially good candidates for bonding in applications where the sealing is critical and the strength is less important. They are often used to seal welds and soldered joints.

- Cyanoacrylics – Cyanoacrylics are one-part, fast-curing, “convenience adhesives.” Normal setting times are two to three seconds and full cures occur within 24 hours at room temperature. These products are popular in tacking and quick-contact operations. The cure of these adhesives is initiated by the presence of surface moisture, even in limited quantities such as humidity in the air. Cyanoacrylics are typically used only on highly specific applications. They provide no significant gap filling. Most laminating and contact adhesives are a subset of the cyanoacrylic adhesive family

WARNING! Always test an adhesive system for compatibility before using it with parts thermoformed from a thermoplastic resin. Also, before working with adhesives, consult product labels and all other safety information provided by the manufacturer. Always be sure to wear any necessary safety clothing or equipment.

Ultrasonic Welding

Ultrasonic welding converts electrical energy into mechanical energy through high-frequency vibration. The vibrations are transmitted through an amplitude booster to the tool or horn, which transfers it to the parts being welded. The vibration melts the thermoplastic and the parts are joined.

When the plastic melts, the vibration is stopped. Pressure is applied to the parts while the plastic solidifies to create a molecular bond between the two parts. Ultrasonic bonding usually takes less than one second.

Decorating & Printing the Formed Part

Part decorating usually begins with the mold design. The thermoforming process can transfer intricate mold details into the hot sheet. As a result, such highly defined details as lettering, logos, figures, and textures can be incorporated.

Textured or embossed surfaces can give a plastic part a different appearance. A combination of color from the original sheet material and textures in the mold can result in a wide variety of attractive options.

Thermoformed parts are also used in applications in markets where high-quality appearance is important. Many methods for surface decoration can be used to differentiate and decorate thermoformed parts. Thermoformed parts can be

- Printed,
- Labeled,
- Painted, and
- Metallized.

Before printing or decorating, it is important to pretest all ink and decorative coatings to see if they are compatible with the thermoplastic.

Printing

Printing is a process of marking a surface to apply decoration or information. Various techniques can be used to apply printing on thermoformed parts made from GE resins, including:

- Screen printing,
- Dyeing,
- Pad transfer,
- Diffusion,
- Flexography,
- Offset printing, and
- Laser printing

Generally, printing requires no surface preparation except for wiping the part clean. Because the printing of film can be done much faster than printing on finished thermoformed parts, preprinted films are often used for roll-fed thermoformers.

Laser System Suppliers

- **Control Laser Corp.**
  7503 Chancelor Drive
  Orlando, FL 32809
  407-438-2500
- **Convergen Tenergy**
  1 Picker Road
  Sturbridge, MA 01566
  508-347-2681
- **General Scanning**
  32 Cobble Hill Road
  Somerville, MA 02143
  617-625-5200
- **Laser Fare Ltd., Inc.**
  1 Industrial Drive South
  Smithfield, RI 02917
  401-231-4400
- **Lasertechnics**
  5500 Wilshire Avenue
  Albuquerque, NM 87113
  505-822-1123
- **Lumonics, Inc.**
  105 Schneider Road
  Kanata, Ontario
  Canada K2K 1Y3
  613-592-1460
- **Lumonics/Laserdyne**
  6690 Shady Oak Road
  Eden Prairie, MN 55344
  612-941-9530
- **Lumonics Laser Systems Group**
  19776 Haggerty Road
  Livonia, MI 48152
  313-591-0101

Pad Printing Equipment Suppliers

- **Autoroll Dennison Corp.**
  River Street
  Middleton, MA 01949
  508-777-2160
- **Markem Corp.**
  150 Congress Street
  Keene, NH 03431
  800-462-7536
- **Printex**
  7755 Arsons Drive
  San Diego, CA 92126
  619-621-2000
- **Service Tectronics Inc.**
  2827 Treat Street
  Adrian, MI 49221
  517-263-0758
- **Transfer Print Foils, Inc.**
  9 Cotters Lane
  P.O. Box 518T
  East Brunswick, NJ
  908-238-1800
- **United Silicone**
  4471 Walden Avenue
  Lancaster, NY 14086
  716-681-8222

Screen Printing Ink Suppliers

- **Colonial Printing Inks**
  180 East Union Avenue
  East Rutherford, NJ 07073
  201-933-6100
- **General Formulations**
  320 South Union Street
  Sparta, MI 49345
  616-887-7387
- **Ink Dezyne Corporation**
  P.O. Box 456
  Sparta, MI 49345
  616-887-8879
- **The Naz-Dar Company**
  1087 North Branch Street
  Chicago, IL 60622
  312-943-8338
- **Nor-Cote Chemical Company**
  P.O. Box 668
  605 Lafayette Avenue
  Crawfordville, IN 47933
  317-362-9180
- **Sericol Midwest Coatings, Inc.**
  20 West 14th Avenue
  N. Kansas City, MO 64116
  816-474-0650
- **Spraylat Corp.**
  716 South Columbus Avenue
  Mt. Vernon, NY 10550
  914-699-3030
- **Westfield Coatings Corporation**
  P.O. Box 815
  Westfield, MA 01086
  413-562-9655

Diffusion Printing Suppliers

- **Borden Decorative**
  1154 Reco Avenue
  St. Louis, MO 63126
  314-822-3880
- **Caprock**
  2303 120th Street
  Lubbock, TX 79423
- **Color-Dec**
  420 Andbro Drive
  Pitman, NJ 08071
  609-589-3800
- **Comtec Inc.**
  7837 Custer School Road
  Custer, WA 98240
  604-536-1114
- **Keytech**
  1280 Jefferson Boulevard
  Warwick, RI 02886
  401-732-7788 Phone
  401-732-5669 Fax
- **Kurz-Hastings**
  Dutton Road
  Philadelphia, PA 19154-3284
  215-632-2300
- **Xpres**
  111 Cloverleaf Drive
  Winston-Salem, NC 20173
  800-334-0425

Sublimation Transfer Ink Manufacturers

- **Coates Screen, Inc.**
  180 East Union Avenue
  East Rutherford, NJ 07073
  201-933-6100
- **Naz-Dar Co./KC Coatings**
  1087 North Branch Street
  Chicago, IL 60622
  312-943-8338
- **Superior Printing Ink Co.**
  70 Bethune Street
  New York, NY 10014
  212-741-3600
- **Union Ink Co., Inc.**
  453 Broad Avenue
  Ridgefield, NJ 07657
  201-945-5766

Labeling

To label thermoplastic parts, labeling machines are used. These include machines that perform:

- Hot stamping,
- Heat transfers,
- Gummed labels, and
- Decals.

Painting

Although GE Plastics engineering resins are available in a wide range of attractive colors, painting can add a special decorative effect or improve the part's function. Some typical reasons for painting a part include:

- Improved chemical, abrasion, and weathering resistance.
- Color matching with adjacent parts or components.
- Electrical conductivity.
- Extra-high gloss or matte finish.
- Textured appearance where molded-in texture is not feasible.
- Covering of surface imperfections caused by processing.

Many paint and primer systems are available that are compatible for use with thermoformed parts.

Paint Suppliers

- **Akzo Coatings**
  Troy, MI
  248-637-0400
- **Bee Chemical Co.**
  Lansing, IL
  708-474-7000
- **Eastern Chem-Lac Corp.**
  Malden, MA
  781-322-8000
- **C.F. Jamison & Co.**
  Bradford, MA
  978-374-4731
- **Koppers Company, Inc.**
  Pittsburgh, PA
  412-227-2103
- **Lilly Industrial Coatings**
  Indianapolis, IN
  317-634-8512
- **PPG Industries**
  Atlanta, GA
  404-761-7771
- **Red Spot Company, Inc.**
  Evansville, IN
  812-428-9100
- **Sherwin Williams**
  Cleveland, OH
  330-528-0124
- **Spraylat Corp.**
  Mt. Vernon, NY
  914-699-3030
- **Tenax Finishing Products**
  Newark, NJ
  973-589-9000
- **U.S. Paint**
  St. Louis, MO
  314-621-0525

Metallizing

Metallizing is a means of applying a metal-like appearance to a plastic part. A primer and base coat is usually applied to the part before the metal is applied. This promotes better adhesion. Metal can be applied by using a vacuum, by sputtering, or by spraying. Metallization is often used to apply electromagnetic interference (EMI) shielding on electronic parts.

Troubleshooting Reference

Problems may arise during thermoforming. Possible responses are indicated below for guidance only. If more complex problems arise, the sheet supplier or GE Plastics should be contacted.

PROBLEM	POTENTIAL CAUSE	SUGGESTED COURSE OF ACTION
Blisters or bubbles	• Heating too rapidly	✔ Lower heater temperature ✔ Use slower heating ✔ Increase distance between heater(s) and sheet
	• Excess moisture	✔ Predry/preheat ✔ Heat from both sides ✔ Do not remove material from moisture-proof wrap until ready to use
	• Uneven heating	✔ Screen by attaching baffles, masks or screen wire ✔ Check for heaters or screens out ✔ Sheet too close to heaters, producing hot spots due to lack of overlap in radiation pattern
Incomplete forming, poor detail	• Sheet too cold	✔ Lengthen heating cycle ✔ Raise temperature of heaters ✔ Use more heaters ✔ If problem occurs repeatedly in the same area, check for lack of uniformity of heat ✔ Add plug assist
	• Clamping frame not hot before inserting sheet	✔ Preheat clamping frame before inserting sheet
	• Insufficient vacuum	✔ Check vacuum holes for clogging ✔ Increase number of vacuum holes ✔ Increase size of vacuum holes – 0.030" (0.76mm) ✔ Increase size or number of vacuum hold tanks
Webbing, bridging or wrinkling	• Sheet too hot causing too much material in forming area	✔ Shorten heating cycle ✔ Increase heater distance ✔ Lower heater temperature
	• Insufficient vacuum	✔ Check vacuum system ✔ Add more vacuum holes or slots ✔ Increase size or number of vacuum hold tanks
	• Material draw excessive in areas of mold or poor mold design or layout	✔ Redesign mold ✔ Use plug or ring mechanical assist ✔ Use female mold instead of male ✔ Add take-up blocks to pull out wrinkles ✔ Increase draft and radii where possible ✔ If more than one article being formed, move them farther apart ✔ Speed up assist and/or mold travel ✔ Redesign grid, plug or ring assists
Nipples on mold side of formed part	• Sheet too hot	✔ Reduce heating cycle ✔ Reduce heater temperature
	• Vacuum holes too large	✔ Plug holes and redrill with smaller bit

PROBLEM	POTENTIAL CAUSE	SUGGESTED COURSE OF ACTION
Too much sag	• Sheet too hot	✔ Reduce heating cycle ✔ Reduce heater temperature
	• Sheet area too large	✔ Use screening or other means of shading or giving preferential heat to sheet, thus reducing relative temperature of center of sheet
	• Orientation	✔ Consider cutting the blank in the other direction relative to part ✔ Consider uniform, higher orientation
	• Inappropriate material grade	✔ Try material with higher hot strength
Sag variation between sheet blanks	• Variation in sheet temperature	✔ Check for air drafts through oven using solid screens around heater section to eliminate draft
	• Sheet made from different resins	✔ Control regrind percentage and quality ✔ Avoid resin mix-ups
	• Variation in gauge between blanks	✔ Check sheet gauge
Chill marks or "drag-off" lines	• Plug assist temperature too low	✔ Increase plug assist temperature ✔ Cover plug with cotton flannel or felt
	• Mold temperature too low, stretching stops when sheet meets cold mold (or plug)	✔ Increase mold temperature ✔ Relieve molds in critical areas
	• Inadequate mold temperature control	✔ Increase number of water cooling tubes or channels ✔ Check for plugged water flow
	• Sheet too hot or cold	✔ Change temperature of sheet
	• Sheet touches cool mold at start of forming, then pulls cooled thickened section over into side wall as forming continues	✔ Screen to provide cooler material on side away from drag line ✔ Selective plug assist to keep thickened section on top of rib
Bad surface markings	• Poor marks due to air entrapment over smooth mold surface	✔ Grit blast mold surface
	• Poor vacuum	✔ Add vacuum holes ✔ If poor marks are in isolated area, add vacuum holes to this area or check for plugged vacuum holes
	• Mold is too hot	✔ Reduce mold temperature
	• Mold is too cold	✔ Increase mold temperature
	• Mold surface too rough	✔ Smooth surface ✔ Change mold material
	• Dirt on sheet	✔ Clean sheet
	• Dirt on mold	✔ Clean mold
	• Dust in atmosphere	✔ Clean thermoforming area; isolate area if necessary and supply filtered air

PROBLEM	POTENTIAL CAUSE	SUGGESTED COURSE OF ACTION
Bad surface markings (cont.)	• Contaminated sheet materials	✔ If regrind is used, be sure to keep clean and store different materials separately
	• Scratched sheet	✔ Separate sheets with paper in storage
Excessive shrinkage or distortion of part after removing from mold	• Removed part from mold too soon	✔ Increase cooling cycle ✔ Use cooling fixtures ✔ Use fan or vapor spray mist to cool part faster on mold
Part warpage	• Removal from clamp too soon	✔ Lengthen cooling time ✔ Add more cooling
	• Stacking and handling of warm parts immediately after forming	✔ Allow parts to cool before excessive handling or stacking
	• Uneven part cooling	✔ Add more water channels or tubing to mold ✔ Check for plugged water flow
	• Poor wall distribution in part	✔ Improve prestretching or plugging techniques ✔ Use plug assist ✔ Check for nonuniformity of sheet heating ✔ Check sheet gauge
	• Poor mold design	✔ Add vacuum holes ✔ Add moat to mold outside trim line ✔ Check for plugged vacuum holes
	• Poor part design	✔ Break up large flat surfaces with ribs where practical
	• Mold temperature too low	✔ Raise mold temperature
Poor wall thickness distribution and excessive thinning in some areas	• Sheet too hot • Formed too slow	✔ Reduce heating or screen in lower sheet temperature ✔ Increase vacuum ✔ Increase number or size of vacuum hold tanks ✔ Use plug assists or bubble blowing technique ✔ Increase material temperature
	• Sheet sag inadequate for part	✔ Use different forming technique such as mounting mold on top platen ✔ Use vacuum snap-back technique ✔ Use reverse vacuum snap-back ✔ Use billow-up plug assist or vacuum snap-back ✔ Use screen to control heating
	• Variations in sheet gauge	✔ Consult supplier regarding his commercial tolerance and improve quality of sheet
	• Hot or cold spots in sheet	✔ Improve heating technique to achieve uniform heat distribution ✔ Check to see if all heating elements are functioning ✔ Form cooler areas by selected screening to reduce draw down in desired area of part; screen or shade as necessary

PROBLEM	POTENTIAL CAUSE	SUGGESTED COURSE OF ACTION
Poor wall thickness distribution and excessive thinning in some areas (cont.)	• Stray drafts and air currents around machine	✔ Enclose heating and forming areas
	• Mold too cold	✔ Provide uniform heating of mold to bring to proper temperature ✔ Check temperature control system for scale or plugging
	• Sheet slipping out of frame	✔ Adjust clamping frame to provide more uniform pressure ✔ Check for variation in sheet gauge ✔ Heat frames to proper temperature before inserting sheet ✔ Check for nonuniformity of heat, giving cold areas around clamp frame ✔ Increase sheet temperature
Nonuniform prestretch bubble	• Uneven sheet gauge	✔ Consult sheet supplier ✔ Heat sheet slowly in a "soak" type heat
	• Uneven heating of sheet	✔ Check heater section for heaters burned out ✔ Check heater section for missing screens ✔ Screen heater section as necessary
	• Stray air drafts	✔ Enclose or otherwise shield or screen machine
	• Nonuniform airflow or cooling from blow air	✔ Baffle air inlet in prestretch box
Shrink marks on part, especially in corner areas (inside radius of molds)	• Inadequate vacuum	✔ Check for vacuum leaks ✔ Add vacuum surge and/or pump capacity ✔ Check for plugged vacuum holes ✔ Add vacuum holes
	• Mold surface too smooth	✔ Grit blast mold surface
	• Part shrinking away	✔ May be impossible to eliminate on thick sheet with vacuum only; use 20-30 psi positive pressure on part opposite mold surface if mold will withstand this pressure
Corners too thin in deep draws	• Sheet too hot	✔ Reduce sheet temperature ✔ Heat with less intensity to give more uniform temperature through thickness
	• Formed too slow	✔ Use more vacuum ✔ Increase size or number of vacuum hold tanks
	• Corners too sharp	✔ Use larger radius
	• Improper forming technique	✔ Check other techniques such as billow-up plug assist, etc.
	• Sheet too thin	✔ Use heavier gauge
	• Variation in sheet temperature	✔ Adjust heating as needed by adding screens to portion of sheet going into corners. (Cross hatch sheet with markings prior to forming so movement of material can be accurately checked)

PROBLEM	POTENTIAL CAUSE	SUGGESTED COURSE OF ACTION
Corners too thin in deep draws (cont.)	• Variation in mold temperature • Improper material selection • Improper part design	✔ Adjust temperature control system for uniformity ✔ Consult sheet supplier or raw material supplier ✔ Check GE Design Group
Part sticking to mold	• Part temperature too high	✔ Increase cooling cycle ✔ Slightly lower mold temperature
	• Not enough draft on mold	✔ Increase taper ✔ Use female mold ✔ Remove part from mold as soon as possible; use cooling jigs
	• Mold undercuts	✔ Use stripping frame ✔ Increase air-eject air pressure ✔ Remove part from mold as early as possible; use cooling jigs ✔ Use removable or retractable undercut segments in mold
	• Wooden mold	✔ Use talc for release ✔ Grease with Vaseline™® ✔ Use Teflon® spray
	• Rough mold surface	✔ Polish corners or all of mold ✔ Use mold release ✔ Use Teflon spray
Sheet sticking to plug assist	• Improper metal plug assist temperature	✔ Reduce plug temperature ✔ Use mold release ✔ Coat plug with Teflon ✔ Cover plug with felt cloth or cotton flannel
	• Wooden plug assist	✔ Cover plug with felt cloth or cotton flannel ✔ Grease with Vaseline ✔ Use mold release compound ✔ Use Teflon spray
Tearing of sheet when forming	• Mold design	✔ Increase radius of corner
	• Sheet too hot	✔ Decrease heating time or temperature ✔ Check for uniform heat ✔ Preheat sheet
	• Sheet too cold (usually thinner gauges)	✔ Increase heating time or temperature ✔ Check for uniform heat ✔ Preheat sheet
	• Material grade	✔ Change material to one with better hot strength
	• Too much mechanical "pull" by mold or plug	✔ Increase sag or "bubble" before forming

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