Lucite® CP continuous process acrylic sheet
Lucite® CPX™ next generation acrylic sheet
Lucite® L cast acrylic sheet

TECHNICAL BULLETIN

Lucite® Acrylic Sheet /Thermoforming

Introduction

Good formability is one of the most important and useful properties of Lucite® acrylic sheet. Since acrylic is a thermoplastic, it becomes soft and pliable when sufficiently heated. In this state, acrylic can be formed to almost any desired shape. On cooling, Lucite® acrylic sheet becomes rigid and retains the shape to which it has been formed.

Forming thermoplastic sheet is probably the simplest type of plastic fabrication. The cost of molds and equipment is relatively low. Both two- and three- dimensional forming of Lucite® acrylic sheet can be accomplished by a number of different methods. The selection of a forming method will depend on the shape, thickness, tolerance and optical quality required for the formed part, as well as, the equipment available and the number of parts to be made. It should be remembered, however, that the success of thermoforming depends primarily on the proper and uniform heating of the sheet and the mold.

Product Description

Lucite® CP is a continuously processed acrylic sheet, which has all of the dependable characteristics associated with fine acrylic such as light weight and excellent clarity. Lucite® CPX™ is a higher molecular weight continuously processed acrylic sheet ideal for thermoforming and fabricating. Lucite® L is a cast acrylic sheet with excellent weatherability and close thickness tolerances.

For further product and application information, refer to Lucite International's Lucite® CP Fabrication Guide and Lucite® L Fabrication Guide.

Index

Outline of Basic Thermoforming Procedure

Following is a summary of basic steps necessary to achieve satisfactory results in thermoforming Lucite® acrylic sheet. A discussion of details and specifics on these points will be found in succeeding sections of this brochure.

1. Clean, Clear Work Area

It is important that the work area is clean and clear of obstructions, dirt, dust, and any other factors which could tend to interfere with handling and forming of Lucite® acrylic sheet. It is especially important that the area be located away from passageways and doorways which could produce drafts resulting in uneven heating and/or cooling of sheet.

2. Proper Equipment

Make sure that the right equipment is on hand for the job which needs to be done. It can be frustrating, costly, and even dangerous to work with temporary solutions. Time spent in doing the job right (whether through commercial equipment or through well-built "home-made" equipment) will normally result in better parts and in greater customer satisfaction.

3. Equipment Inspection

Once Lucite® acrylic sheet is withdrawn from the oven, only a short period of time exists during which successful forming can be accomplished. It is especially important, therefore, that all mechanical equipment (ovens, pumps, hydraulics, pressure lines, clamps, etc.) be checked for proper operation and that molds and forms be checked for defects. Molds or forms should be kept clean and brushed off before each piece is formed. When not in use, forms should be stored carefully to protect them from denting, chipping, or warping as any such defects will produce corresponding imperfections on the formed Lucite® acrylic sheet.

4. Shrinkage Allowance

Lucite® CP continuous process acrylic sheet and Lucite® CPX™ acrylic sheet will shrink up to 5% in the machine direction when heated, depending on the thickness of the material that is being thermoformed. Lucite® L cast acrylic sheet will shrink approximately 2% in length and width when heated. If it is desired to thermoform to an exact final size, allowance should be made for this shrinkage.

5. Forms and Molds

Forms and molds for Lucite® acrylic sheet may be made of wood, plywood, metal, gypsum, Masonite, die stock, thermosetting plastic resins or any combination of these materials. To provide dimensional accuracy, mold dimensions should be made 1% larger than nominal part dimensions, as the change from forming temperature to room temperature (thermal contraction) will cause the piece to shrink by approximately 1%.

6. Provision for Clamping

In order to provide adequate clamping area, Lucite® acrylic sheet should be cut somewhat larger than actual part dimensions.

7. **Removal of Masking**

Thermoforming Lucite® acrylic sheet with polyfilm masking has never been easier. Our polyfilm masking is designed specifically for thermoforming and in most cases can be left on throughout the entire forming process.

If Lucite® acrylic sheet with adhesive paper masking is used for thermoforming, the acrylic sheet must first be clean and free of masking paper and adhesives. Immediately prior to heating, masking paper should be removed. Adhesive residue can be removed by dabbing with the gummed side of the masking paper. Any residue still remaining on the Lucite® acrylic sheet surface may be removed by wiping with a soft clean cloth (muslin, cheesecloth, cotton) dampened with isopropyl alcohol. If only a small area of sheet will be heated for forming (i.e., strip heater forming), only the masking in this area need be removed.

8. General Forming Conditions

Proper and uniform heating is the most critical factor in the thermoforming process. Lucite® acrylic sheet must be heated uniformly to a pliable condition which can perhaps best be described as resembling a sheet of gum rubber. Forming at too low a temperature can result in excessive internal stresses (and perhaps cracking). Heating Lucite® acrylic sheet to too high a temperature may result in surface imperfections (bubbles, etc.) and poor tear resistance during forming. Optimum parts are obtained when the sheet is heated in a manner which produces the lowest thermal gradient across the sheet thickness.

9. Sheet Temperature

Lucite® CP continuous process acrylic sheet should be heated to temperatures of 290° -320°F. Lucite® CPX™ acrylic sheet should be heated to temperatures of 290° -340°F. Lucite® L cast acrylic sheet should be heated to temperatures of 290° -350°F for forming. The precise temperature for optimum thermo formability of any particular part can be determined only through practice and experience.

10. Oven Temperature

Lucite® acrylic sheet is a good thermal insulator and heat travels rather slowly from the surface to the interior of the sheet. For this reason, one should allow as much time as practical for heating Lucite® acrylic sheet to the proper forming condition. Oven temperature should be held constant at 20° - 40°F above the nominal sheet temperature and time should be varied to arrive at the proper forming state. Once a time/temperature condition has been found which produces acceptable forming performance, it can be easily duplicated with Lucite® acrylic sheet for succeeding parts. The exceptional thickness uniformity of Lucite® acrylic sheet provides a constancy of thermoforming performance which has heretofore not been generally available in acrylic sheet of this optical quality. Slightly longer heating cycles at lower temperatures will provide more uniform heating of acrylic sheet.

11. Handling Lucite® Acrylic Sheet

In handling Lucite® acrylic sheet, operators should wear soft lint-free gloves for protection from burns and also to prevent part blemishes which may result from fingerprints on either hot or cold Lucite® acrylic sheet. Sheets should be gripped in the clamping area only if possible.

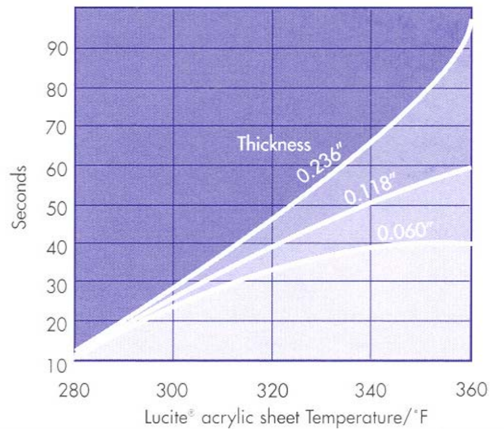
12. Forming

A variety of different forming techniques are described below. Irrespective of the specific technique being used, it is important that considerable attention be paid to detail during the actual forming operation. Only a short period of time exists during which sheet can be properly formed and any inattention to detail will result in poorly formed parts and/or damaged sheet. Many of these important factors have been discussed above (clean work area, proper equipment and sheet temperature, etc.). Others are summarized below:

- Sheet should be securely clamped before applying pressure or vacuum

- Vacuum or pressure should be applied gradually but steadily to provide uniform stretching of sheet.
- It is important that joints in the vacuum port be sealed against air leaks which could cause uneven cooling of the part.
- When using pressure, it is important to use a deflector to distribute air flow uniformly. This also prevents air from impinging directly on a portion of the sheet which could cause premature cooling of this area and thereby result in non-uniform forming, or unusual distortion.
- The sheet should be completely formed before it cools below the minimum forming temperature (275° - 280°F). Approximate time available for forming after oven removal is shown in Figure 1.

FIGURE 1 Approximate maximum forming time available after removal of Lucite® from oven. Room air 70° - 80° F



13. Cooling

Formed Lucite® acrylic sheet should be allowed to cool slowly and uniformly on the mold. Covering the freshly formed part with a soft blanket will help provide slow, uniform cooling. If sheet has been tightly clamped, it is important that clamps be loosened slightly as the part cools to allow for shrinkage which occurs upon cooling. Forced air cooling should never be used, as it results in highly stressed parts, which in turn leads to crazing and cracking.

14. Removing from Mold

Formed Lucite® acrylic sheet should be cooled below 165°F before removing the part from the mold.

15. Reforming

If an error is made in forming, it may be possible to recover the Lucite® acrylic sheet by reheating and reforming. Because of the property of "elastic memory", parts from Lucite® acrylic sheet will return to their original "flat" shape if reheated. Reforming will not remove scratches or "mark-off" surface blemishes but slight forming errors can easily be recovered if care has been taken during the initial forming process.

To reform a part of Lucite® acrylic sheet simply bring the sheet up to proper forming temperature and form as usual.

Heating Equipment and Methods

Lucite® acrylic sheet should be heated to its forming temperature with a minimum of temperature gradient throughout the sheet. Protective coatings or masking paper should always be removed from the forming area before heating. Two basic types of heating methods are normally used for forming Lucite® acrylic sheet - forced circulating air heating and radiant heating.

1. Forced-Air Heating
Forced circulating air ovens generally provide uniform heating at a constant temperature with the least danger of overheating the acrylic sheet. Electric fans should be used to circulate the hot air across the sheeting at velocities of 150-250 feet per minute. Suitable baffles should be used to distribute the heat evenly throughout the oven and to prevent localized overheating of sheet. Heating may be done with gas or electricity. Gas ovens require heat exchangers to prevent the accumulation of soot from the flue gas. Electric ovens can be heated with a series of 1,000 watt strip heating elements. An oven with a capacity of 350 cubic feet, for example, will require approximately 25,000 watts of input. About one-half of this input is required to overcome heating losses through the insulation, leaks and door usage. An oven insulation at least two inches thick is suggested. Oven doors should be narrow to minimize heat loss, but at least one door should be large enough to permit reheating of formed parts which may require reforming. The oven should have temperature indicators and automatic controls so that any desired temperature in the range of 250° to 450°F can be closely maintained. Additionally, temperature recording devices are desirable.

Lucite® L cast acrylic sheet can be hung vertically. This can be accomplished by hanging the sheets of acrylic on overhead racks designed to roll along a monorail mounted in the oven roof or in a portable unit. Precautions should be taken so that sheets cannot fold or come in contact with one another. A series of spring clips or a spring channel can be used for securely grasping the sheet along its entire length. Such ovens are available from several manufacturers. Forced-Air heating generally results in longer heat cycles.

Lucite® CPX™ acrylic sheet can be hung vertically; however, please consult with Lucite International Technical Service before doing so. Lucite® CP continuous process acrylic sheet is not recommended for vertical oven application.

2. Infrared Heating
Infrared radiation can heat Lucite® acrylic sheet three to ten times faster than forced-air heating.

This type of heating is often used with automatic forming machines, for thin sheeting, or where a minimum cycle time is important. Temperature control, however, is much more critical and uniform heating is more difficult to obtain by this method. Acrylic plastic absorbs most of the infrared energy on the exposed surface, which can rapidly attain temperatures of over 500°F. The center of the sheet is heated by the slower conduction of heat from the hot surface. Two sided heaters are recommended to ensure uniform heating of Lucite® acrylic sheet, especially in sheets which are 0.125 inches (3 mm) and above in thickness. Thicknesses up to 0.250 inches (6 mm) can be used by simultaneously exposing both sides of the sheet to infrared heating.

Infrared radiant heat is usually supplied by reflector-backed tubular metal elements, resistance wire coils or a bank of either ceramic or quartz infrared heating elements. More uniform heat distribution can sometimes be accomplished by mounting a fine wire-mesh screen between the sheet and the heat source. In addition, a device to control the energy input, such as a variable transformer, should be available. The infrared heater units are often mounted on a movable rig for overhead heating of sheet clamped horizontally in a frame located near or over the forming mold. This arrangement permits the sheet to be formed as soon as its proper forming temperature has been attained. For an even distribution of heat, the sheet should be positioned about eighteen inches from the heating elements. If infrared lamps are used, the lamps should be spaced seven to eight inches apart, center to center, in rows long enough to cover the longest sheet to be heated.

Infrared heating is not recommended for large areas over which very uniform temperatures are needed in order to obtain the best possible optics.

Molds

One of the biggest advantages of thermoforming is the relatively low cost and ease with which a mold can be built from a wide variety of materials. In many cases, the molds can be designed and built in the sheet forming shop. Mold design and materials selection will depend on the size and number of parts to be produced, as well as the quality required for the finished part.

1. **Mold Design**

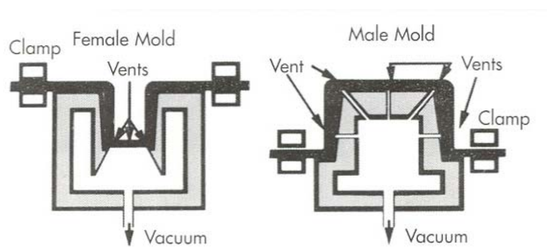
With proper mold design, high quality parts of acrylic can be formed to contour tolerances of less than + 1/8 inch. The following design suggestions should be considered when building a mold for the forming of Lucite® acrylic sheet:

A. Generally, a male mold is easier to use, costs less to build, and is more suitable for forming deep draw parts than a female mold. Ordinarily, a female mold should not be used for parts requiring a draw of greater than one-half the width of the part. A female mold is often used when the pre-decorated surface or the best optical surface must be on the concave side of the formed part, which does not contact the mold.

An additional consideration regarding mold selection (i.e., whether the mold should be male or female) relates to the thickness contour desired in the formed part. Depending on which part of the sheet first comes to contact with the mold, the part thickness may be varied to accommodate an individual situation.

This phenomenon is shown in the schematic below. The effect is exaggerated in Figure 2 in order to adequately illustrate the point. Other techniques for controlling thickness uniformity (plug assist, etc.) are described in a later section of this bulletin.

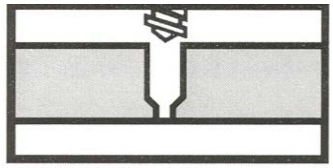
FIGURE* 2 *Choosing Male* or *Female Molds



B. The mold must be properly vented with a sufficient number of holes so that the heated sheet can be pushed, blown or drawn uniformly and rapidly into the deepest mold contours. Vent holes should be located in the deepest recesses of the mold and in any areas where air might *become* trapped. Vent holes should be small enough to prevent hole marks on the plastic. Holes of .020 inch diameter are usually satisfactory for forming 1/8 inch thick Lucite® acrylic sheet. Smaller holes might be desirable when forming thinner sheets.

More effective vacuum control can be achieved if the holes are back-drilled to approximately 1/8 inch from the mold surface as shown in the following diagram. Sometimes molds are designed so venting occurs around shims, thus eliminating the need for holes. (See Figure 3.)

FIGURE 3 Mold Venting



C. When close control of mold temperature is required, the mold should be cored to permit temperature controlled water or oil to circulate freely throughout the mold. Control units designed to pump water or oil at a given temperature through the mold coring are commercially available. Cast aluminum is a good mold material where rapid heat transfer is desired.

D. When the final dimensions of the part are critical, over-sized molds must be built to compensate for the shrinkage of the sheet when cooled to room temperature. Thermal shrinkage of approximately 1% should be allowed for the cooling of acrylic from its forming temperature to room temperature.

E. A slight dish or dome effect in large flat sections of the mold will allow the sheet to stretch over this area, thus preventing the small ripples or bumps which sometimes appear in parts formed on large, perfectly flat forms.

F. A draft angle of 3° or more on the walls and all protruding sections of the mold will facilitate the removal of the formed plastic from the mold.

G. Right-angle edges and sharp corners in a formed part are areas where stress concentrations can occur. The strength will be greater in a part designed with curved edges, corners and fillets.

H. Weaker or thinned sections of the part can be strengthened by forming reinforcing ribs or designs into these areas. Ribs can also be used to increase the rigidity of large flat areas.

I. Undercuts should be avoided unless the mold is designed to permit easy removal of the formed part.

J. If a permanent insert is to be molded into the part the difference in thermal coefficients of expansion of the insert and the acrylic should be considered. The formed acrylic could be cracked by a tight-fitting insert which has a greatly different thermal expansion characteristic.

K. Mold surfaces can be covered with *cotton* flannel, felt, velvet, suede or other materials to decrease mold mark-off.

L. The surface of a mold can be roughened or sandblasted to avoid entrapped air which can cause pits or blemishes.

2. Mold Materials

Both male and female molds used for forming acrylic plastic sheet can be made from wood, plaster, plastic or metal. Selection of a material to build a mold depends primarily on the quality required and number of parts to be made.

Wood - Almost any well-dried hard wood such as hickory, birch, cherry or maple can be used to form parts from Lucite® acrylic sheet. To prevent dimensional changes with changes in humidity, wooden molds should be sealed with casein, a phenolic varnish, urethane or an epoxy resin diluted with methyl ethyl ketone. For the best surface, the side grain, rather than the end grain of the wood should be exposed to the surface of the mold. Molds made from pressed or laminated wood have a longer life. The life of a wooden mold can often be extended for production runs of up to several thousand pieces by reinforcing the mold edges with metal.

Plaster - Plaster molds can be cast from a low-shrinkage, high-strength gypsum composition reinforced with wire mesh, steel rods, glass fiber or other materials which do not absorb moisture. The plaster is cast over a master pattern which is often the wooden pilot mold.

If a wooden master is used the surface can be covered with a thin sheet of waterproof material such as rubber to prevent the wood from absorbing moisture from the plaster. Greasing the surface of the wood or clay master will facilitate the removal of the plaster mold after curing. The plaster mold should be allowed to cure for five to seven days at room temperature. If the surface on the master form is smooth, often no further finishing of the cast plaster mold is necessary. Surface coatings of phenolic, urethane or epoxy resins will provide a harder, more durable wearing surface. Production runs of over a quarter of a million parts have been formed with plaster molds.

Considerable caution must be exercised to avoid chipping the plaster surface when drilling vent holes in the mold. Drilling can sometimes be eliminated and vent holes made by inserting wires through the fresh-poured gypsum and the removing the wires after the plaster has set.

Plastic - Plastic molds are more costly than plaster or wood molds, but they offer greater durability, longer life, smoother surfaces, and better dimensional stability. They are cast usually from phenolic or epoxy resins.

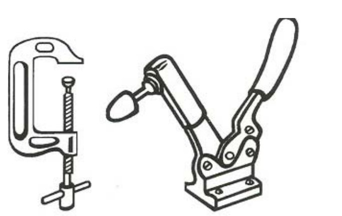
Metal - For long production runs, or for air-pressure or mechanical forming which involve relatively high pressures, metal molds are often used. Molds cast by foundry techniques from aluminum, bronze, or low melting alloys, and molds machined from steel, brass, or bronze can be used.

Metal molds are the most expensive, but they have a longer life, better surface, lower maintenance costs, and better dimensional stability than molds made from other materials. In addition, they can be cored for improved temperature control. When using metal molds, care should be taken to avoid cooling the part too rapidly.

3. Mold Clamping Devices

In most forming operations, a means to clamp the hot sheet of Lucite® acrylic sheet against the form or mold is required. Rapid and secure clamping is often a critical operation for successful forming. For small jobs, "C" clamps are reliable although their use is slow; hence, faster action toggle clamps are preferred. For the highest production rates, clamping rings actuated by air cylinders can be used. (See Figure 4.)

FIGURE 4 Clamps



Satisfactory clamping rings can be cut from Masonic die stock or a rigid phonemic laminate. Metal rings are undesirable because of the high thermal conductivity of the metal which can chill the edges of the plastic. Wooden rings are usually undesirable because they will vary in dimensions with atmospheric changes.

Forming Machines

A forming machine consists of four basic components:

1. A heater to raise the plastic to its forming temperature.
2. Vacuum, air pressure, or mechanical devices for pulling or pushing the heated plastic sheet into or over a mold.
3. A clamping device or frame to hold the plastic during heating, forming and cooling.
4. A base or platen for holding the mold.

Auxiliary components and equipment include pressure or vacuum control units, sheet trimming devices, mold heating units, as well as mechanical and automatic devices for moving and controlling heaters, molds, plugs and sheeting.

Single-stage, multi-stage and continuous forming machines are designed to perform one or a combination of three basic forming operations.

1. Vacuum Forming

The majority of commercial forming machines employ vacuum as the forming agent. Vacuum is generally supplied from 5 to 100 cubic foot capacity accumulator tanks. These tanks are evacuated to a vacuum level of 24 to 29 inches of mercury by high-volume pumps with capacities ranging from 2 to 150 cubic feet per minute. The size of the pump and tank should have sufficient capacity to maintain a vacuum level of at least 22 inches of mercury during the production run. Standard steel pipe of one to three inches in diameter is normally used for the vacuum line connections. A section of flexible metal-reinforced vacuum hose between the accumulator tank and forming equipment will permit freer and more convenient movement of the mold setup. The vacuum line should have both a quick opening valve so that the full tank vacuum can be applied instantaneously to the mold, and a throttle valve so that evacuation from the mold can be regulated at slower rates.

2. Pressure Forming

An air compressor with supply tank can be used to supply air pressure to the mold. A pressure gauge and a reducing valve should be available for accurate regulation of the air pressure. A baffle system should be installed between the air line and the mold so that the air is uniformly distributed as it enters the pressure chamber and also so that the air will not blow directly on the heated sheet.

3. Mechanical Forming

Hydraulic or pneumatic pressure can be used to move the dies, molds or mechanical devices required to form the heated sheet.

Selection of the proper forming equipment will depend on the particular thermoforming job.

The selection of a heating unit which has a good temperature control system and will provide uniform heating of the sheet is probably the most important requirement to consider for successful forming. Most batch-type forming units use forced-air oven heating. Newer, automatic vacuum forming machines use radiant heating.

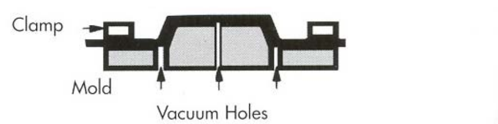
Three-Dimensional Forming Techniques

Techniques for three-dimensional forming of plastic generally require vacuum, air pressure, mechanical pressure, or a combination of these to manipulate the heated sheet into the desired shape or mold. The basic forming techniques most commonly used for acrylic plastic sheet are described in Figure 5.

1. Vacuum Forming

Heated sheets of Lucite® acrylic sheet may be drawn by vacuum into or over a mold. A clamping or hold-down ring should be used to provide a vacuum seal between the plastic and the mold flange. For uniform vacuum drawing, a sufficient number of vent holes should be evenly distributed in the deepest recesses of the mold. The even draw-down and good registration which can be obtained by vacuum forming make this technique suitable for forming pre-distorted, printed silk-screened sheets where accurate and reproducible moldings and placement of colors are necessary. (See Figure 5.)

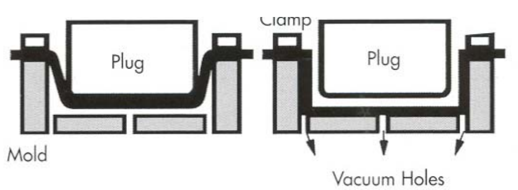
FIGURE* 5 *Vacuum Forming Male Mold



2. Vacuum Forming with Plug Assist

Straight vacuum drawing the sheet into a mold tends to leave a part with sides thicker than the bottom. Pushing the sheet with a plug leaves the bottom thicker than the sides. The combination of the two techniques, therefore, yields more uniform wall thicknesses and thereby permits deeper draws. (See Figure 6.)

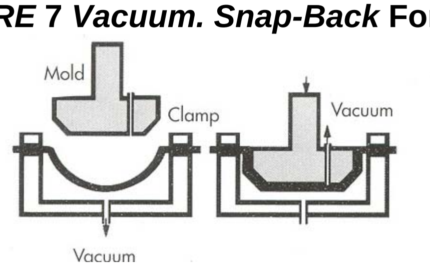
FIGURE 6. Vacuum. Forming With Plug Assist Female Mold



3. Vacuum Snap-Back Forming

This technique is valuable for forming parts of Lucite® acrylic sheet which require a very uniform wall thickness and less mold mark-off The heated sheet is pulled into a vacuum box. The vacuum is then slowly released and, due to the elastic memory characteristic of Lucite® acrylic sheet, the sheet returns toward its original form and settles back against the vented mold plug. Sharper definitions and formation of reverse projections can be obtained if a vacuum is then pulled through the vent holes of the mold plug. (See Figure 7.)

***FIGURE* 7 *Vacuum. Snap-Back* Forming**

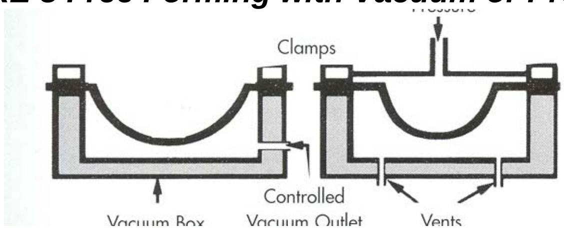


4. Free Forming with Vacuum or Pressure

Finished parts of Lucite® acrylic sheet which require the best possible optical properties, such as skylights and airplane canopies, can be formed without molds by free blowing the sheet into bubbles. The shape of the finished piece is determined by the size and shape of the clamping ring and by the size of the bubble. Shapes, however, are limited to those having contours of free-blown bubbles. For free-forming, vacuum is easier to control and is preferred over pressure.

However, when pressures greater than the one atmosphere are required, then free-forming by pressure is required. In general, free-forming requires more skill and experience to make parts of accurate dimensions than do the other forming techniques. Photo-electric cells and solenoid valves are often used to regulate the pressure and to control the dimensions of the part. (See Figure 8.)

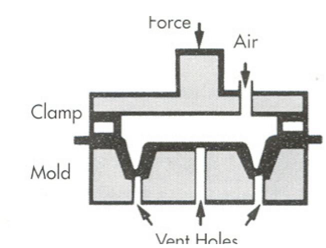
FIGURE 8 Free Forming with Vacuum or Pressure



5. Pressure Forming

This technique permits the hot sheet of plastic to be shaped into or over molds with a greater pressure than is obtainable by vacuum forming. Parts with sharp definition and good dimensional tolerances can be made by this method. However, the greater pressures will cause greater mold mark-off. If high pressures are used, molds must be made of metal, epoxy resins, or other materials which can withstand the greater pressure. (See Figure 9.)

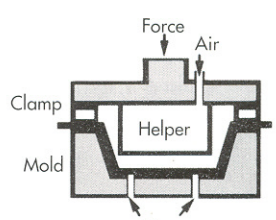
FIGURE* 9 *Pressure Forming Female Mold



6. Pressure Forming with Plug Assist

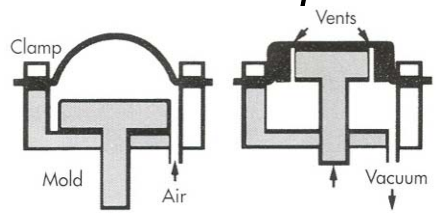
The plug assist technique is used to reduce thinning at the bottom of a deep-drawn part. The plug pre-stretches the hot sheet of plastic into the mold before the pressure is applied. (See Figure 10.)

FIGURE 10 Pressure Forming Female Mold with Helper



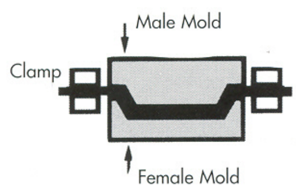
7. Pressure Snap-Back Forming
This method permits forming sheet into deep-drawn parts. Careful control of the blow pressure is required. A photo-electric cell with a solenoid valve may be used to cut the pressure when the hot sheet is blown to the proper height. Vacuum may be used to accentuate the snap-back. (See Figure 11.)

***FIGURE 11 Pressure Snap-Back* Forming**



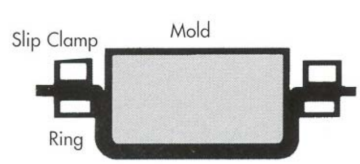
8. Mechanical Match Male and Female Mold Forming
Lucite® acrylic sheet may be formed like metal by pressing the hot sheet between a male and female mold to produce very accurate and close-tolerance parts. This technique generally produces a heavy mold mark-off on both sides of the sheet. (See Figure 12.)

FIGURE 12 Mechanical Forming Male and Female Dies



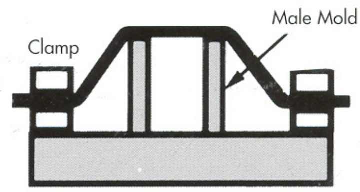
9. Mechanical Slip-Ring Forming
This technique decreases the amount of wall thickness variation when plastic is deep-drawn. The hot sheet is fitted loosely between a clamp and a slip-ring. As the plug mold is mechanically forced into the hot sheet, slippage occurs which decreases the draw-down of the sheet. When sufficient sheet has slipped into the mold, the ring is clamped tight, vacuum is applied, and the draw is completed without further slippage. Wrinkling of the sheet around the ring sometimes limits the amount of material which can slip. Mark-offs from the ring and clamp will be on the walls of a part formed by this method. (See Figure 13.)

FIGURE 13 Mechanical Forming with Slip-Ring



10. Mechanical Ridge Forming
Sometimes parts of acrylic can be formed with only partial molds. This method permits parts to be formed with less mold mark-off and improved optical qualities by minimizing the amount of contact between the formed plastic and the mold. (See Figure 14.)

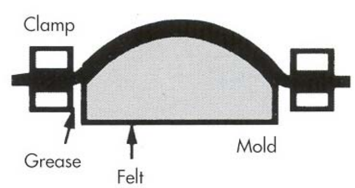
FIGURE 14 Ridge Forming



11. Mechanical Grease Forming

Application of grease such as 'Cazar' No.2 to a mold covered with a 1/16 inch thick felt or flannel will eliminate mold mark-off. A grease layer 1/16 to 1/8 inch thick melted into a liquid blanket will insulate the hot plastic sheet from the mold. Formed acrylic of the highest optical qualities can be made by this method. This technique is slow since the mold must be re-greased after each molding, and the grease must be cleaned from the formed parts of Lucite® acrylic sheet. Grease can be cleaned from acrylic with solvents such as hexane, aliphatic naphtha or kerosene. Solvents which can cause crazing, such as carbon tetrachloride, alcohols, gasoline and acetone, should be avoided. The grease must be heated to approximately the Lucite® acrylic sheet forming temperature and the form should be heated to about 170°F. (See Figure 15.)

FIGURE 15 Grease **Forming**



12. Mechanical Embossing

Patterned or textured surfaces may be formed in plastic. Relatively high air or mechanical pressures and heated metal molds are required to form uniform pattern with good definition.

Various features of these basic forming methods can be combined to create a virtually infinite number of possible forming techniques. Good knowledge of these basic methods is necessary to permit selection of the best forming technique.

Troubleshooting Guide for Thermoforming

The following guide provides a rapid check-list for suggested solutions in forming difficulties which might occur.

Problem	Possible Causes	Suggested Remedies
1. Bubbles in sheet	a. Sheet overheated b. Excessive moisture	a. Reduce heating time or temperature b. Store sheet in dry area, Dry sheet in oven at 140° - 175°F for 4-12 hours
2. Poor surface finish	a. Scratched sheet b. Mold mark-off	a. Proper storage and handling of sheet. Mask sheet or insert paper between sheets. Polish sheet to remove scratches. b Finish or grease mold. Reduce sheet or mold temperature.
3. Wrinkling of hot sheet	a. Sheet too hot b. Mold too hot	a. Reduce heating time or temperature. b. Permit more time between cycles for mold to cool. Circulate cooling liquid through mold coring. Cool mold with uniform air blast.
4. Sticking of formed part to mold	a. Mold too hot. b. Non-uniform removal c. Mold has insufficient edge taper or too deep undercuts	a. Same as 3b. b. Pull formed part straight away from mold of parts from mold with a uniform force on all sides. Blow air through vent holes to uniformly loosen part. c. Taper edges at least three degrees. Eliminate or decrease depth of undercuts.
5. Inadequate draw-down	a. Insufficient heating of sheet b. Insufficient vacuum c. Improper mold design	a. Increase heating time and temperature b. Check for plugged vent holes and the need for additional holes. Need for a larger vacuum pump or tank. c. Design mold which requires less draw-down or less intricate definition
6. Distortion after forming	a. Hot sheet removed from mold while still soft b. Improper mold design c. Non-uniform heating of sheet d. Non-uniform cooling of part	a. Increase mold cooling time b. Design mold to give greater rigidity to the formed part. Large areas of the mold should be slightly convex rather than flat or concave. c. Provide uniform heating from properly designed heater. Keep sheet at a uniform distance from the heating source. Distribute heat more uniformly with a fine wire-mesh screen baffle d. Cool formed part in a draft-free area.
7. Crazed or brittle part	a. Insufficient heating of sheet b. Non-uniform heating of sheet c. Mold too cold d. solvent attack	a. Increase heating time and temperature b. Same as 6c c. Warm mold and/or assist plug d. Avoid cleaners, lacquers, thinners, paint removers which contain solvents that can attack or dissolve acrylic surfaces.

Sources of Supply

The following list of supplies and sources is provided by Lucite International as a customer service. It is not intended to be a complete listing of either products or sources. A much more comprehensive listing can be found in the Modern Plastics Encyclopedia, published annually by McGraw-Hill Inc.

Many of the products listed here are available locally. Before contacting these suppliers directly it is suggested that the prospective user check with their authorized Lucite® acrylic sheet distributor or dealer or other local suppliers. Lucite International makes no warranties, either expressed or implied that products referred to here in will perform satisfactorily with Lucite° acrylic sheet. In all cases, manufacturers should be contacted for their recommendations or warranties.

Forced Hot Air Ovens

- The National Drying Machinery Company
  2190 Hornig Rd,
  Philadelphia, PA 19114
  215-464-6070
- Rolen Manufacturing CO,
  3131 Kansas Ave.
  Riverside, CA 92507
  909-683-7302

Strip Heaters

- Chromalox Division of Emerson Electric
  641 Alpha Drive
  Pittsburgh, PA 15238
  412-967-3800
- Watlow Electric Manufacturing Co.
  12001 Lackland Rd
  St. Louis, MO 63146
  314-878-4600

Commercial Forming Machines

- Brown Machine Company
  330 Ross St
  Beaverton, MI 48612-9101
  517-435-7741
- Plasti-Vac. Inc.
  214 Dalton Ave
  Charlotte, NC 28206-3116
  704-334-4728
- Shuman Company
  PO Box 240906
  Charlotte, NC 28224-0906
  704-525-9980
- Maac Machine Co, Inc
  590 Tower Blvd
  Carol Stream, IL 60188
  630-665-1700

Mold Temperature Control Units

- Sterling Inc, Industrial Control Division
  5200 West Clinton Ave
  Milwaukee, WI 53223
  414-354-0970
- Cole Parmer Instruments
  625 East Bunker Court
  Vernon Hills, IN 60061
  847-549-7600

Vacuum Pumps & Compressors

- Ingersol-Rand
  Woodcliff, NJ
  201-573-9071
- Nash Engineering Co
  9 Trefoil Drive
  Trunbull, CT 06611
  203-459-3900
- Gast Mfg Corp, Div of IDEX
  PO Box 97
  Benton Harbor, MI 49023
  616-926-6171

Infrared Heaters

- Trent, Inc.
  201 Leverington Ave.
  Philadelphia, PA 19127
  215-482-5000
- Fostoria Industries
  1993 North Main St>
  Fostoria, OH 44830
  419-435-9201
- Solar Prod. Infrared Heater Co.
  228 Wanaque Ave.
  Pompton Lakes, NJ 07442
  973-966-2000

Electrical Solenoids

- Asco Power Tech
  56A Hanover Rd
  Florham Park, NJ 07932
  973-966-2000
- General Electric Co – Industrial Heating Dept.
  1 Progress Rd
  Shelbyville, IN 46176
  800-626-2002

Mold Makers

- Miller Mold Co.
  3320 Bay Road
  Saginaw, MI 48603
  517-793-8888
  517-435-7741
- Portage Casting & Mold Inc
  2901 Portage Rd.
  800-356-5337
- Tooling Technology
  Fort Laramie, OH
  937-295-3677
  Fax 937-295-3677

Mold Materials

Gypsum Plaster

- US Gypsum Company
  101 South Wacker Dr
  Chicago, IL 60605
  312-606-9155

Epoxy Compounds

- ITW Devcon Corp
  30 Endicott Street
  Danvers, MA 01923
  978-777-1100

Ren Plastics

- CIBA Specialty Chemicals
  4917 Dawn Ave.
  East Lansing, MI 48823
  800-367-8793

Low Melting Alloys

- Cerro Metal Products
  PO Box 388
  Bellefone, PA 16823
  814-355-6217

Mold Grease

Cazar 1 and 2

- Exxon Company USA
  7720 York Rd
  Baltimore, MD 21204
  410-563-5108

Indopol H-100

- Amoco Chemical
  150 west Warrenville Rd
  Naperville, IL 60563
  877-701-2726

Mold Coverings

Flocked Rubber

- Archer Rubber Company
  Milford, MA 01757
  508-473-1870
- Ohio Flock-Core Co.
  7200 Northfield Rd
  Walton Hills, OH 44146
  216-439-1480

Felt

- National Non-Wovens
  PO Box 150
  Easthampton, MA 01027
  413-527-3445

Vacuum Suction Cups

- Stratco-Vacuum Handling Co
  4619 West Roscoe
  Chicago, IK 60641
  773-545-0555

Vacuum Valves

- McCanna Company
  400 maple Ave
  Carpentersville, IL 60611
  508-481-4800

Clamps

Spring and Hinged Clamps

- Adjustable Clamp Co
  417 North Ashland Ave
  Chicago, IL 60522
  312-666-0640

Toggle Clamps

- De-Sta-Co. Industries
  A Dover Resource Co.
  2121 Cole St.
  Bringham, MI 48009
  248-594-5600

Spray Equipment

- ITW Industrial Finishing
  Binks/Devilbiss
  195 Industrial Blvd
  Glendale Heights, IL 60139
  Tech Support 888-992-4657
  Cust Service 877-849-9564
- Venus Gusmer Inc.
  Subsidiary of Gusmer Mach.
  1862 Ives Ave
  Kent, WA 98032
  800-448-6034

Spray Masking Compounds

- Spraylat Corporation
  716 S. Columbus Ave
  Mt. Vernon, NY 10550
  914-699-3030

Antistatic Equipment

- Simco Inc.
  2257 North Penn Rd.
  Hartfield, PA 19440
  215-822-2171
- Exair Corp.
  1250 Century Circle No.
  Cincinnati, OH 45246
  512-671-3322

Paints

Grip-Flex®

- Wyandotte Sign Finishes
  PO Box 255
  Norcross, GA 30071

Lacryl®

- Spraylat Corporation
  716 S. Columbus Ave
  Mt. Vernon, NY 10550
  914-699-3030

Inks

- Nazdar
  1087 No. North Branch
  Chicago, IL 60622
  312-587-2416

Saw Blades for Acrylics

- Forrest Mfg. Co.
  457 River Rd
  Clifton, NJ 07014
  973-473-5236
  800-733-7111

Router Bits

- Onsrud Cutter
  800 Liberty Drive
  Libertyville, IL 60048
  847-362-1560

Low Metal Alloys

- CERRO Metal Products
  PO Box 388
  Bellefone, PA 16823
  814-355-6217

Filler (Ti-Hydrated Alumina)

- ALCOA
  Isabella Street
  Pittsburgh, PA 15219
  412-553-4545
- Great Lakes Mineral
  2855 Coolidge Highway
  Troy, MI 48084
  313-649-3700

LUCITE INTERNATIONAL
7275 GOODLETT FARMS PARKWAY
CORDOVA, TN 38016-4909

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