Working With

PAL-G™

PAL-G UV™

PETG Sheets

PALRAM

This brochure describes methods for handling and processing PALGLAZE SHEETS. The data is based on experience aquired by Palram Industries and other end users of PALGLAZE SHEETS. This information, while accurate to the best of our knowledge, should be regarded as a recommendation only, and no liability for the consequences of its use will be accepted by Palram Industries.

C O N T E N T S

A. Introduction

The manufacture of plastic articles from PALGLAZE flat sheet normally involves secondary fabrication operations, including sawing, drilling, bending, decorating, and assembling. This pamphlet covers the properties and characteristics of PALGLAZE which need to be taken into account if these secondary operations are to be performed successfully. For your reference, the properties of a typical 3 mm (0.12 in.) sheet are listed in the Appendix at the end of this pamphlet (page 28).

In non-thermoforming applications, the masking film should only be removed after fabrication and installation is completed. In general, it is possible to carry out all thermoforming fabricating procedures, including hot bending and vacuum forming, with the masking in place. **It is imperative to indicate that you intend to carry out a procedure which entails heating the sheet, when ordering PALGLAZE**. This will enable you to receive masking with markings placed on the edges (or without markings if so required). If there are markings, then it is necessary to remove the masking prior to heating. In this case , it is necessary to verify that the surfaces are clean before processing. **In any case, it is absolutely necessary to carry out a trial on a sample sheet from each production batch to verify that it is possible to heat and/or thermoform the sheet without removing the masking.**

B. Fabrication

1. Machining Guidelines

PALGLAZE SHEET can be worked with most tools used for machining wood or metal. Tool speeds should be adjusted so that the plastic sheet does not melt from frictional heat. In general, the highest speed at which overheating of the tool or plastic does not occur, will give the best results.

It is important to keep cutting tools sharp at all times. Hard, wear-resistant tools with greater cutting clearances than those used for cutting metal are suggested. High-speed or carbon-tipped tools are efficient for long runs and provide accuracy and uniformity of finish. Since plastics are poor heat conductors, the heat generated by machining operations must be absorbed by the tool and carried away by a coolant. A jet of air directed on the cutting edge aids in cooling the tool and in removing chips. Plain or soapy water is sometimes used for cooling unless the trim scrap is to be reused.

2. Drilling

Drills designed especially for plastics are available, and their use is suggested. Standard twist drills for wood or metal can be used; however, they require slower speeds and feed rates to produce a clean, non-gummed hole. Acceptable holes with minimal shavings have been produced on a $^3/_4$ HP, 5 speed drill press operating at 500 RPM.

Twist drills for plastics should have 2 flutes, a point with an included angle of 60˚ to 90˚, and a lip clearance of 12˚ to 18˚.

Wide, highly polished flutes are desirable since they expel the chips with low friction, and thus tend to avoid overheating and consequent gumming. Drills with substantial clearance on the cutting edge of the flutes make smoother holes than those with less clearance. Drills should be backed out often to free chips, especially when drilling deep holes. Peripheral speeds of twist drills for plastics ordinarily range from 30.5 to 61 m (100 to 200 ft) per minute. The rate of drill feed into the plastic sheet generally varies from 0.254 to 0.635 mm (0.01 to 0.025 in.) per revolution.

Note: When drilling, be sure to hold or clamp the part securely to prevent it from cracking or slipping, and as such, presenting a safety hazard to the operator.

3. Tapping

Conventional 4-flute taps can be used for cutting internal threads in plastic sheet when a close fit is required. Such taps, however, have a tendency to generate considerable heat during the tapping operation. A high-speed, 2-flute tap should offer longer life and greater tapping speed than a conventional tap, as well as provide clearance for chip discharge. Flutes should be ground so that both edges cut simultaneously; otherwise the thread will not be uniform. Cutting edges should be 85˚ from the centerline, giving a negative rake of 5˚ on the front face of the lands so that the tap will not bind in the hole when it is backed out. It is desirable to have some relief on the sides of threads.

4. Milling

PALGLAZE SHEET can be machined with standard high-speed milling cutters for metal, provided they have sharp edges and adequate clearance at the heel.

Climb cutting is a milling operation that gives a good machine finish on plastics. In climb milling, the work moves in the same direction as the rotating cutter. Satisfactory results can be achieved using a 15.9 mm (5/8 in.) diameter bit at 500 rpm with a travel of 127 mm (5 in.) per minute. Climb milling requires lubrication with plain or soapy water.

5. Sawing

Any of the following saw types, commonly used for wood or metal, should be satisfactory for cutting PALGLAZE SHEET: circular saws, band saws, saber saws, jigsaws, hacksaws, or handsaws. However, some designs are better suited than others for sawing plastics because they produce smoother or faster cuts. Circular saw and band saws usually produce the best surfaces, and they can be used in most sawing operations. Blade design plays an have zero rake and some set. For a curved cut, the blade should be narrower and have more set than for a straight cut. The blade must be kept sharp to prevent melting or chipping of the plastic, and the blade guide should be placed very near the cut to minimize vibration.

A circular saw is preferred to a band saw for straight cuts even though it tends to generate more heat. A circular saw should be operated at approximately 2,400 to 3,000 linear m (8,0000 to 10,000 linear ft) per minute with carbide-tipped saw blades having 3 to 5 teeth per 25 mm (1 in.) and should have plenty of set or be hollow ground. A perforated saw blade will run cooler than a solid blade. It is essential that the spindle bearing be tight, so that the saw will run true.

Several different types of blades have been evaluated for each type of saw, and the following suggestions are made based on the smoothness and general cut appearance. The saw blades listed in Table 1 below are commercially available.

Table1: Sawing Recommendations

Type of Cut	Tool	Blade Type	Blade Parameters	Blade Speed
Straight	Circular Saw (Preferred for straight cuts)		18.4 cm ($7^{1}/_{4}$ in.) diam., 40 tooth carbide-tipped cutoff or 18.4 cm ($7^{1}/_{4}$ in.) diam., 200 tooth plywood	
			4500 rpm	
	Band Saw	1.27 cm (1/2 in.)	3 to 6 teeth per 25 mm (1 in.), skip	610 m/min (2,000 ft/min)
	Saber saw or jigsaw	Finish cutting blade	7 teeth per 25 mm (1 in.)	
	Handsaw	Crosscut	8 or 10 pt.	
Curved	Band Saw	1.27 cm (1/2 in.)	3 to 6 teeth per 25 mm (1 in.), skip	610 m/min (2,000 ft/min)
Trimming and deflanging	Router	Carbide tipped, double fluted straight	0.95 cm (3/8 in.) diameter 23,000 rpm	
	Radial arm or table saw	25.4 cm (10 in.)	72 teeth, triple chip grind 3,450 rpm	

Note: Be sure to hold or clamp the part securely while sawing to prevent chattering which can cause cracking.

6. Shearing and Punching

Shearing and punching are suitable methods for cutting PALGLAZE sheet. A shear will produce a straight-edge cut whereas a punch can produce holes of almost any desired size.

Power shears can be used to cut PALGLAZE in thicknesses up to approximately 0.254 cm (0.100 in.); for thicker sheet, saw cutting is

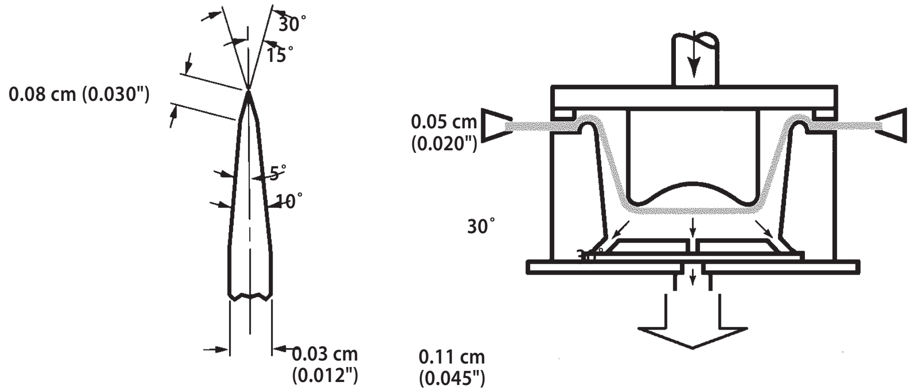
Punches may be used when a fairly rough edge is satisfactory. Hand-operated punches are useful for small holes; however, power operated punches are normally used for holes larger than approximately 0.64 x 5.08 cm (1/4 x 2 in.). Cracking and chipping can be reduced by heating the sheet to approximately 38 ˚C (100 ˚F); however, some allowance for hole shrinkage due to cooling may be necessary. Sawing, drilling, and routing are preferable to punching when thicknesses are greater than approximately 0.254 cm (0.1 in.).

7. Die Cutting

PALGLAZE SHEET can be cut satisfactorily with steel rule dies, which are ribbons of steel that may vary from 0.08 to 0.254 cm (0.03 to 0.100 in.) in thickness by 1.27-cm (1/2-in.) wide and are sharpened on one edge. They are generally mounted in slots of appropriate shape that are cut into wood blocks and are relatively inexpensive. The steel rule must be sharpened or replaced fairly often.

Figure 1 depicts two steel rule designs that work equally well in sheet gauges up to 0.254 cm (0.100 in.). Hardness may vary from 45 to 55 Rockwell C and can be dependent on the degree of bending required in fabrication.

Figure 1. Steel-rule die designs for cutting PALGLAZE SHEET.



Presses designed for die cutting should be adjusted to cut completely through the plastic sheet with a stroke that will stop before damaging the cutting rule. A make-ready procedure is used to shim areas of the die to ensure that all areas cut through the plastic sheet uniformly. All presses should have a softer steel cutting plate (30-35 Rockwell C) to prevent contact with the press bed.

The cutting surface is normally a 0.05 cm to 0.32 cm (0.020-0.125 in.) thick steel plate. A 0.15 mm to 0.20 mm (6-8 mil) kraft/carbon paper is taped to the plate, and the die is then carefully lowered so that the entire cutting area is marked. Test die cutting is then alternated with shimming of rule areas until a full, uniform cut through the plastic sheet is obtained.

It is also important to cut in the same place each time and to keep the cutting dies as sharp as possible.

Figure 2 illustrates a typical setup for using a steel rule die, and a shearing assembly is shown in Figure 3.

Figure 2. Diagram of steel rule die assembly.

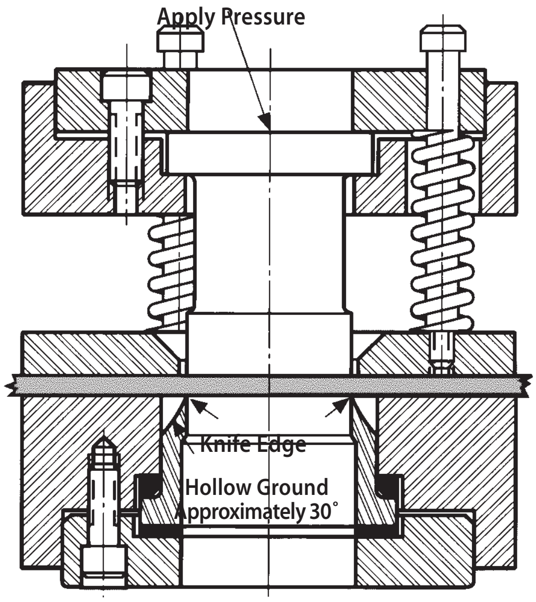
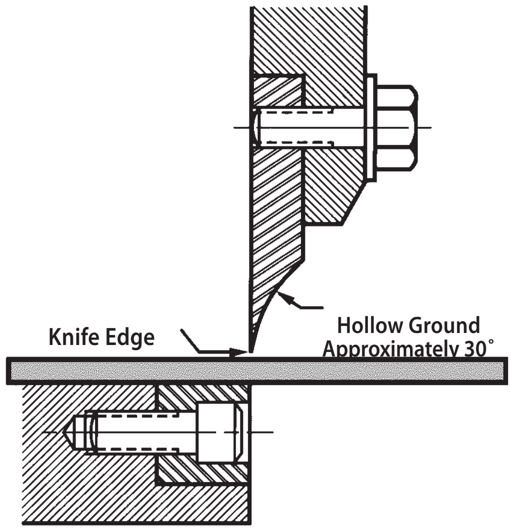


Figure 3. Diagram of shearing assembly.



A die press must have adequate power to achieve the desired cut. The shear strengths of PALGLAZE SHEET that are shown in Table 2 can be used with the following formula to calculate the required press tonnage:

Table 2: Shear Strength Requirements

Sheet Thickness, mm (in.)	**Shear Strength**, MPa (psi)
2 (0.06)	57.6 (8,354)
3 (0.12)	56.5 (8,195)
6 (0.24)	46.1 (6,686)

$$F\ (\text{metric ton}) = \frac{\text{Shear strength (MPa)} \times \text{perimeter of cut (cm)} \times \text{thickness (mm)} \times 10^{-5}}{9.8\ \text{m/s}^2 \times 1000\ \text{kg/metric ton}}$$

or

$$F\ (\text{tons}) = \frac{\text{Shear strength (psi)} \times \text{perimeter of cut (in.)} \times \text{thickness (in.)}}{2{,}000\ \text{lb./U.S. ton}}$$

For example, 38.1 x 38.1 cm (15 x 15 in.) sheet of 3.048 mm (0.120 in.) thick PALGLAZE SHEET would have a shear strength of 56.5 MPa (8,195) psi. The press tonnage would be:

$$F = \frac{56.5\ \text{MPa} \times 152.4\ \text{cm} \times 3.048\ \text{mm}}{9.8\ \text{m/s}^2 \times 1000\ \text{kg/metric ton}} = 26.8\ \text{metric ton}$$

or

$$F = \frac{8{,}195\ \text{psi} \times 60\ \text{in.} \times 0.120\ \text{in.}}{2{,}000\ \text{lb./U.S. ton}} = 29.5\ \text{U.S. ton}$$

8. Laser Cutting

PALGLAZE SHEET can be cut by laser beam in thicknesses up to 0.47 cm (0.87 in.). A laser may be used to make intricate holes and complex patterns, or it can be controlled to merely etch the plastic. Holes and cuts produced by a laser have a slight taper; the cuts are clean and precise, with a finished appearance. Tolerances can be controlled more closely with a laser than with conventional machining operations. Laser power and travel speed must be optimized to minimize "whitening" of the **PALGLAZE SHEET** while cutting.

9. Routing

Routers with sharp two-flute straight cutters produce very smooth edges. They are useful for trimming the edges of flat or formed parts, particularly when the part is too large or irregular in shape for a band saw. Portable, overarm, and under the table routers work equally well. The plastic sheet should be fed to the router slowly to avoid excessive frictional heating and shattering. The router or plastic sheet, whichever is moving, must be guided with a suitable jig. Compressed air can be used during the routing operation to cool the bit and aid in chip removal.

C. Forming

1. Cold Bending

Brake forming and cold bending can be used to produce simple shapes from PALGLAZE SHEET; the permissible degree of bending is dependent on both sheet thickness and rate of deflection. Cold bending of gauges over 0.254 cm (0.100 in.) will likely result in high stress levels.

2. Thermoforming

There are a number of different thermoforming techniques that can be used to force PALGLAZE SHEET, once heated, into the shape of a mold by mechanical, air pressure, or vacuum forces. Both male (plug) and female (cavity) molds are used. Tooling can range from low-cost plaster molds to expensive water-cooled steel molds, but cast aluminum is more commonly used. Other materials including wood, gypsum, and epoxy can also be used.

Forming processes to be discussed include straight vacuum snap-back, pressure-bubble vacuum snap-back, trapped-sheet contact pressure, free, and mechanical.

Items produced by thermoforming include light fixtures, instrument panel components, tote trays, housewares, toys, and a variety of different transparent enclosures.

3. Heating before Thermoforming

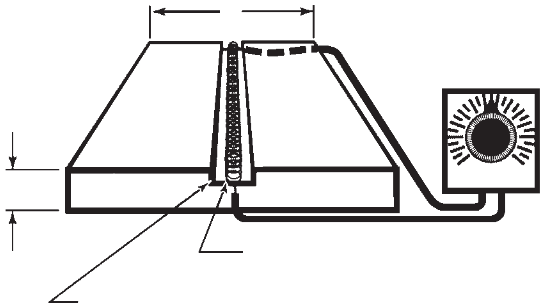
PALGLAZE PETG sheets do not require pre-drying before thermoforming. Only very short heating cycles are required, and the sheet does not have to sag considerably during heating. A common mistake with thermoformers, who are used to polycarbonate or acrylic, is a tendency to overheat the sheet. This results in a loss of impact resistance although the sheet still appears clear and glossy. A very simple test is the "hammer test". This entails delivering a strong blow to the formed article. If it breaks or shatters, this is a sign of overheating. The heating time should be shortened (or the temperature lowered). The same rule applies to other heating processes, such as Hot Line Bending or Drape Forming. Always limit the heating time to the minimum required, especially when high impact resistance is required.

For example, when a clear 3 mm PALGLAZE SHEET is heated on top and bottom at 450˚C for 70 seconds, there results a clear glossy, high definition, and high impact resistant product that passes the "Hammer Test". The same sheet, when heated at the same temperature for 120 seconds, becomes brittle, breaking in the "Hammer Test".

4. Hot Bending

PALGLAZE SHEET can be bent on a small radius by preheating an area on both sides with an electric strip heater and then quickly bending the sheet along the heated line. Thicker gauges [above 0.375 cm (0.125 in.)] may need to be turned periodically during the heating cycle. The side of the sheet that is to form the inside angle should be heated first and the outer side last. When the optimum sheet temperature is reached [slightly over 105 ˚C (225 ˚F)] and a slight resistance to bending is noticeable, the part can be readily formed. If bending is performed too cold, stresses will be created that will result in a brittle part; however, overheating can cause bubbles in the bend area. Strip heaters are available from plastic supply houses, or they can be built as depicted in Figure 4.

Figure 4. Heat bending device



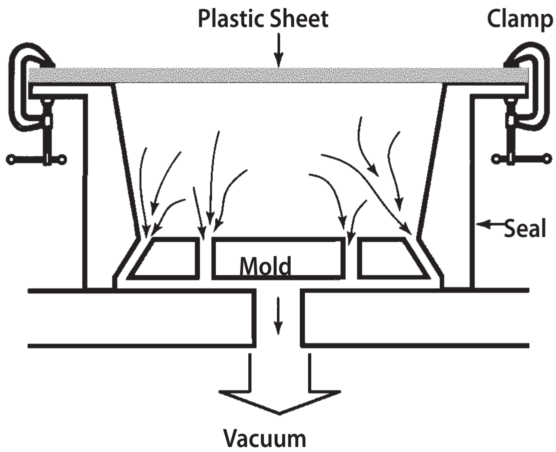
5. Straight Vacuum Forming

Vacuum forming is the most versatile and widely used forming process. The equipment costs less and is simplest to operate than most pressure or mechanical techniques. In straight vacuum forming, the PALGLAZE SHEET is clamped in a frame and heated. When the hot sheet is in an elastic state, it is placed over the female mold cavity. The air is then removed from the cavity by vacuum, and atmospheric pressure then forces the hot sheet against the contours of the mold. When PALGLAZE SHEET has cooled sufficiently, the formed part can be removed.

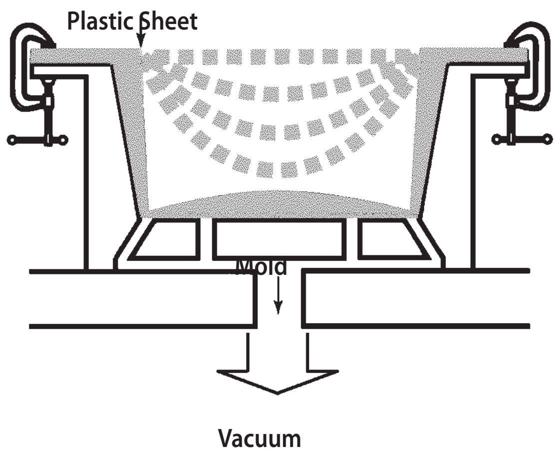
Thinning at the upper edges of the part usually occurs with relatively deep female molds. Thinning is caused by the hot sheet being drawn to the center of the mold first. The sheet at the edges of the mold must stretch the most and thus becomes the thinnest section of the formed item. Straight vacuum forming is normally limited to simple, shallow designs. See Figures 5A, 5B, and 5C.

Figures 5A, 5B, and 5C. Straight vacuum forming

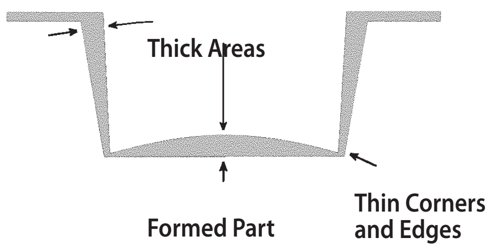
A. A clamped, heated sheet is forced down into the mold by air pressure after a vacuum is drawn in the mold.



B. Plastic sheet cools as it contacts the mold.



C. Areas of the sheet that touch the mold last are the thinnest.



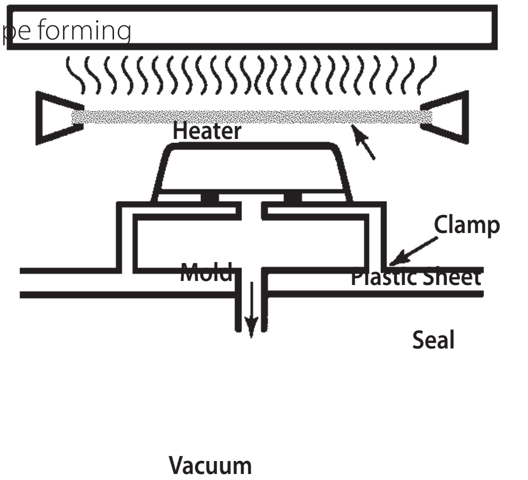
6. Drape Forming

Drape forming is similar to straight vacuum forming except that after the PALGLAZE SHEET is framed and preheated, it is mechanically stretched, and a pressure differential is then applied to form the sheet over a male mold. In this case, however, the sheet touching the mold is close to its original thickness. It is possible to drape-form items with a depth-to-diameter ratio of approximately 4 to 1; however, the technique is more complex than straight vacuum forming. Male molds are easier to build and generally cost less than female molds; but, male molds are more easily damaged.

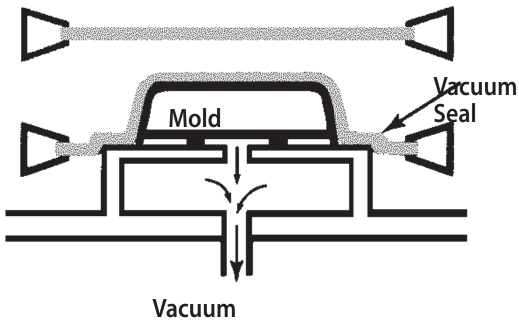
Drape forming can also be used with gravitational force alone. For multicavity forming, female molds are preferred because they do not require as much spacing as male molds. See Figure 6A, 6B, and 6C.

Figures 6A, 6B, and 6C. Drape forming

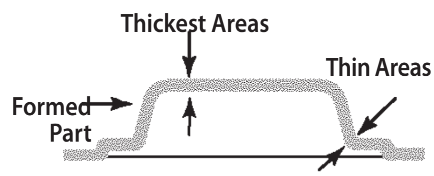
A. Clamped, heated plastic sheet can be pulled over the mold, or the mold can be forced into the sheet.



B. Once the sheet has formed a seal around the mold, a vacuum is drawn to pull the sheet tightly against the mold surface.



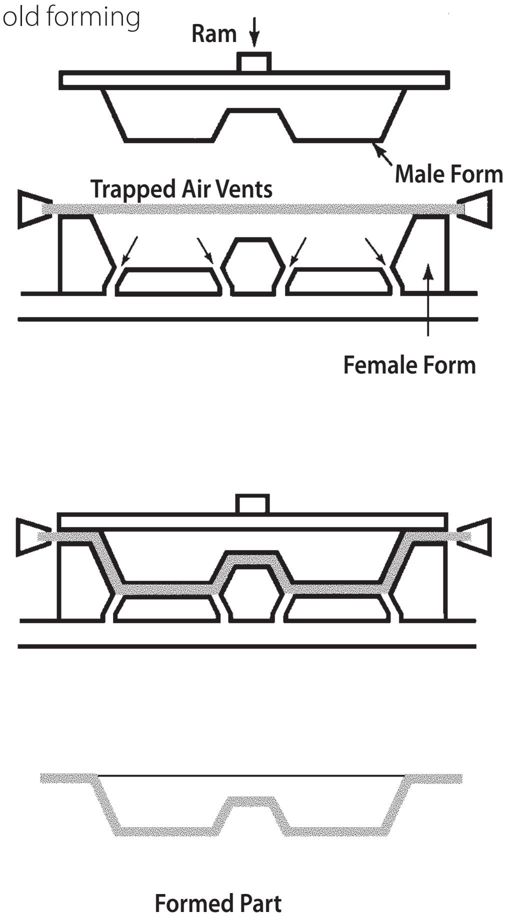
C. Final wall thickness distribution in the molded part.



7. Matched-Mold Forming

Match-mold forming is similar to compression molding in that heated PALGLAZE SHEET is trapped between male and female dies made of wood, plaster, epoxy, or some other material. Although they cost more, water-cooled matched molds produce more accurate parts with close tolerances. See Figures 7A and 7B.

Figures 7A and 7B. Matched-mold forming



A. The heated plastic sheet can be clamped over the female die, as shown, or draped over the mold form.

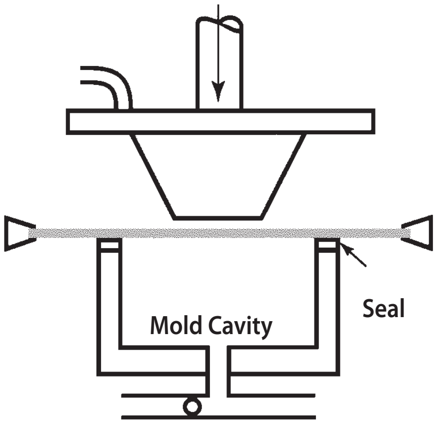
B. Vents allow trapped air to escape as the mold closes and forms the part.

8. Pressure-Bubble Plug-Assist Vacuum Forming

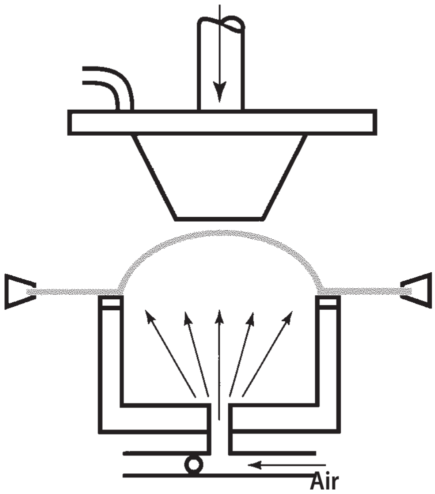
The pressure-bubble plug-assist vacuum forming technique can be used when PALGLAZE SHEET is to be formed into deep articles that must have good thickness uniformity. The sheet is placed in a frame and heated, and controlled air pressure is used to create a bubble. See Figure 10A, 10B, 10C, and 10D. When the bubble has been stretched to a predetermined height, the male plug-assist (normally heated) is lowered to force the stretched sheet into the cavity. Plug speed and shape can be varied for improved material distribution.

Figures 8A, 8B, 8C, and 8D. Pressure-bubble plug-assist vacuum forming

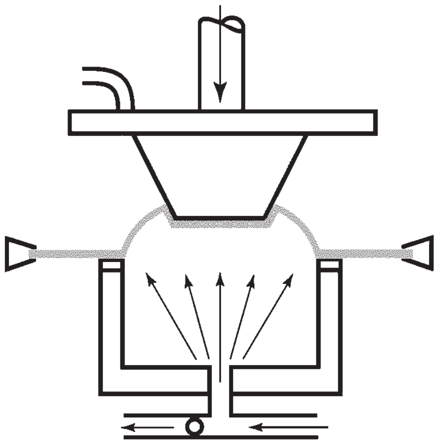
A. The plastic sheet is heated and sealed across the mold cavity.



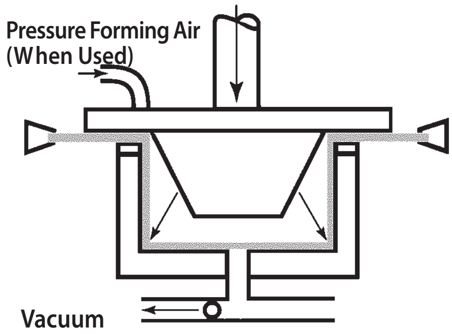
B. Air is introduced, blowing upward into an evenly stretched bubble.



C. A plug shaped roughly to the cavity contour presses downward into the bubble, forcing it into the mold.



D. When the plug reaches its lowest point, vacuum is drawn to pull the plastic against the mold walls. Air can be introduced from above to aid forming.

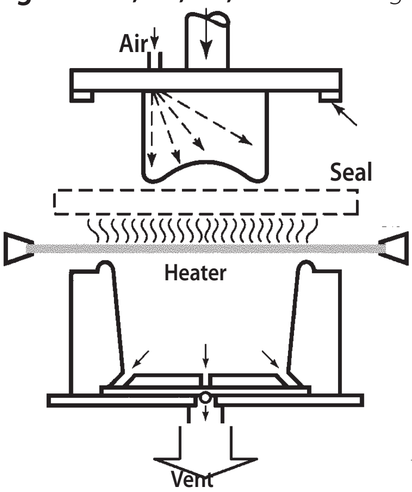


The plug is made as large as possible so that the plastic material is stretched close to the shape of the finished product. The plug should penetrate 75 to 85 percent of the mold cavity depth. Air pressure is then applied from the plug side while a vacuum assist is being drawn on the cavity. The female mold must be vented to allow escape of trapped air.

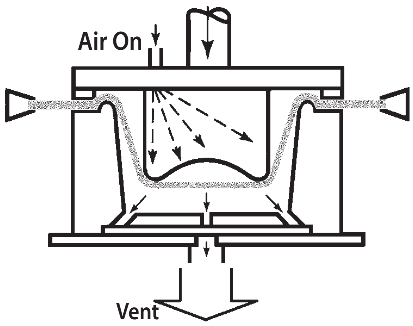
9. Plug-Assist Pressure Forming

Plug-assist pressure forming is similar to plug-assist vacuum forming in that a plug forces the hot PALGLAZE SHEET into a female cavity. Air pressure applied from the plug then forces the plastic sheet against the walls of the mold. Plug design and plug speed can be varied to optimize material distribution. See Figure 9A, 9B, 9C, and 9D.

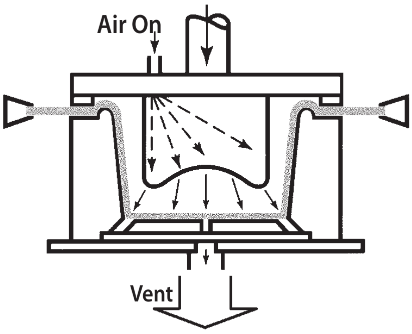
Figures 9A, 9B, 9C, and 9D. Plug-assist pressure forming



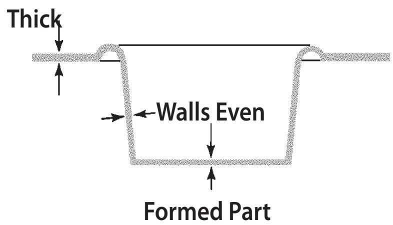
A. Heated, clamped plastic sheet is positioned over the mold cavity.



B. As the plug touches the sheet, air is allowed to vent from beneath the sheet,



C. As the plug completes its stroke and seals the mold, air pressure is applied from the plug side, forcing the plastic against the mold.



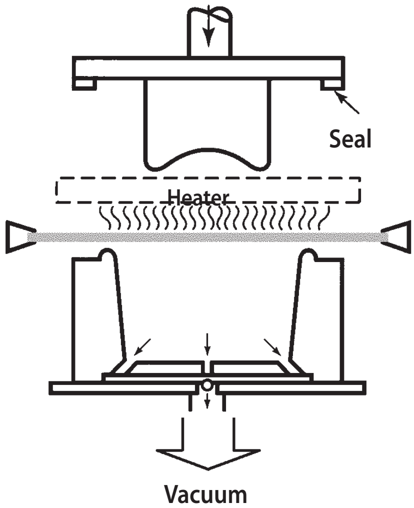
D. Plug-assist pressure forming is capable of producing products with uniform wall thickness.

10. Plug-Assist Vacuum Forming

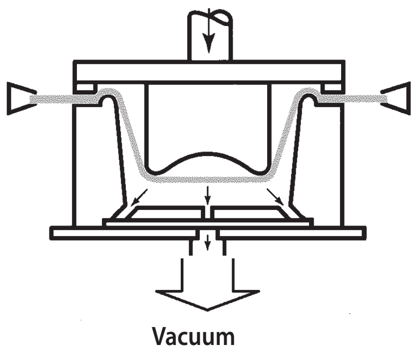
Corner or periphery thinning of cup- or box-shaped articles can be prevented by use of a plug assist to mechanically stretch and pull additional plastic material into the female cavity. The plug should be 10 to 20 percent smaller than the mold and should be heated to just under the forming temperature of the sheet. Once the plug has forced the hot sheet into the mold cavity, air is drawn from the mold to form the part.

Plug-assist vacuum forming and plug-assist pressure forming (see previous section) allow deep drawing and permit shorter cooling cycles and good wall thickness control. See Figure 10A, 10B, 10C, and 10D.

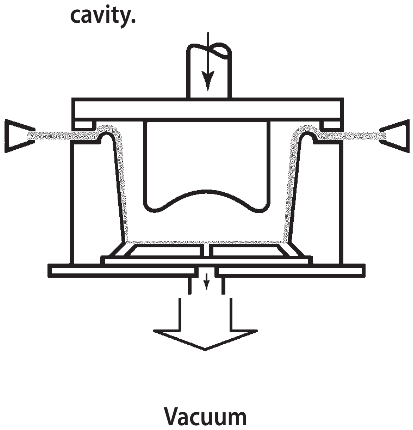
Figures 10A, 10B, 10C, and 10D. Plug-assist vacuum forming



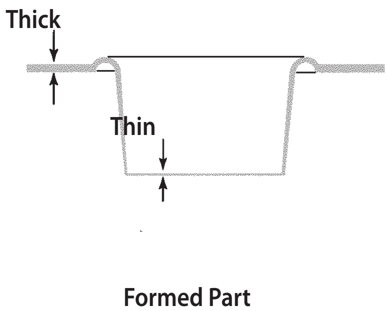
A. Heated, clamped plastic sheet is positioned over the mold cavity.



B. A plug, shaped roughly like the mold cavity, plunges into the plastic sheet to prestretch it.



C. When the plug reaches the limit of its travel, a vacuum is drawn in the mold cavity.

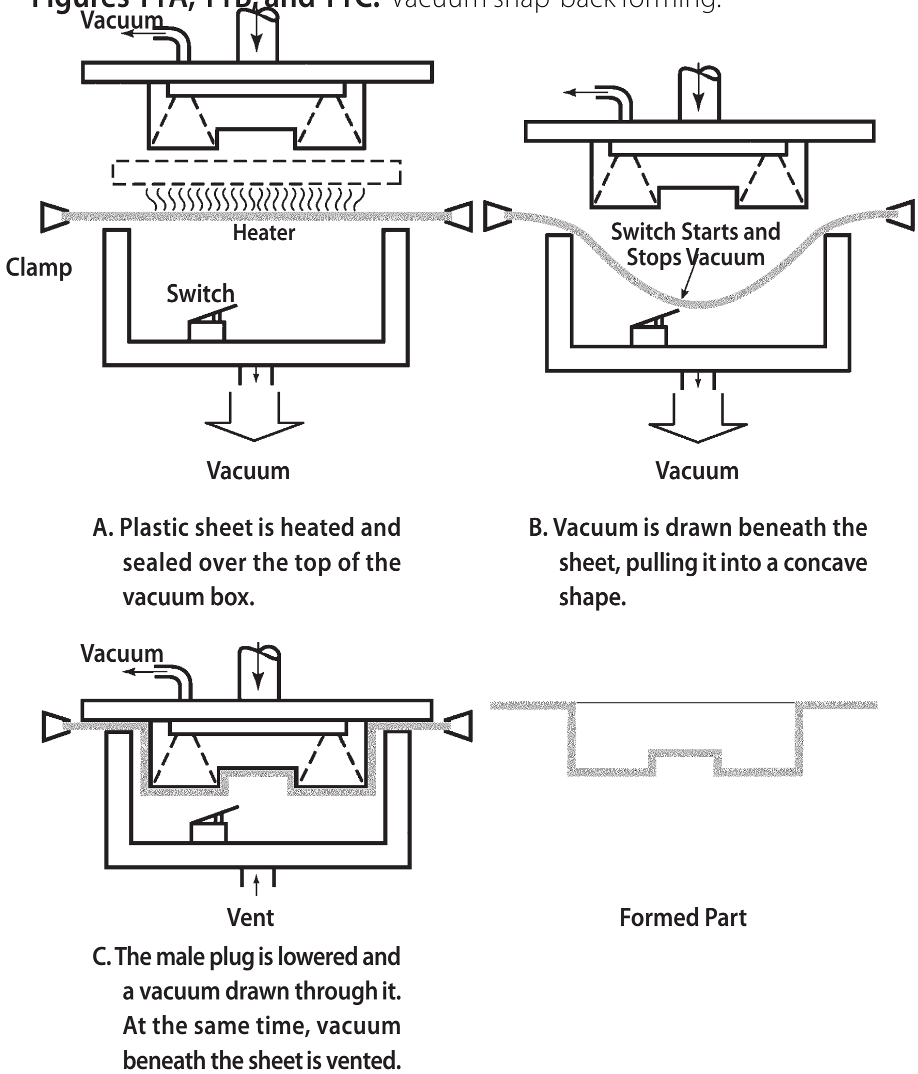


D. Portions of the plug that touch the sheet first will form thickened areas due to a chilling effect.

11. Vacuum Snap-Back Forming

In vacuum snap-back forming, the hot PALGLAZE SHEET is placed over a box, and a vacuum is drawn to force a bubble into the box. The male mold is then lowered and the vacuum released, causing the plastic sheet to snap-back around the mold. A vacuum assist may also be drawn in the male mold. Vacuum snap-back forming is useful for complex parts with recesses. See Figures 11A, 11B, and 11C.

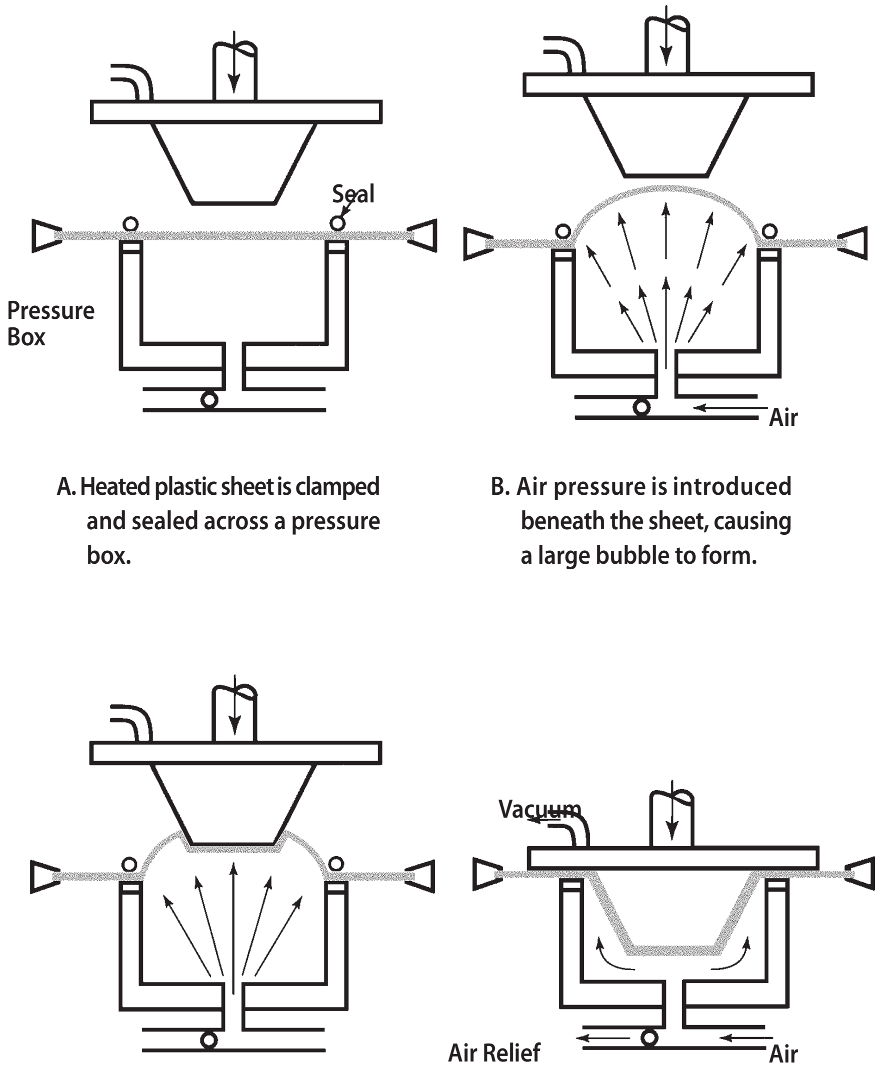
Figures 11A, 11B, and 11C. Vacuum snap-back forming.



12. Pressure-Bubble Vacuum Snap-Back Forming

In pressure-bubble vacuum snap-back forming, the PALGLAZE SHEET is heated and stretched 35 or 40 percent by air pressure. The male mold is then lowered, and vacuum is applied to the male mold while air pressure is forced into the female cavity. The hot sheet then snaps back around the male mold. Pressure-bubble vacuum snap-back forming permits deep drawing and forming of complicated parts; however, the equipment is complex and costly. See Figures 12A, 12B, 12C, and 12D.

Figures 12A, 12B, 12C, and 12D. Pressure-bubble vacuum snap-back forming.



A. Heated plastic sheet is clamped and sealed across a pressure box.

B. Air pressure is introduced beneath the sheet, causing a large bubble to form.

C. A plug is forced into the bubble while air pressure is maintained at a constant level.

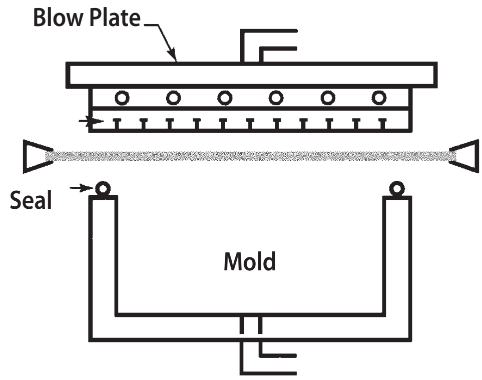
D. Air pressure beneath bubble and a vacuum at the plug side create a uniform draw.

13. Trapped-Sheet Contact-Heat Pressure Forming

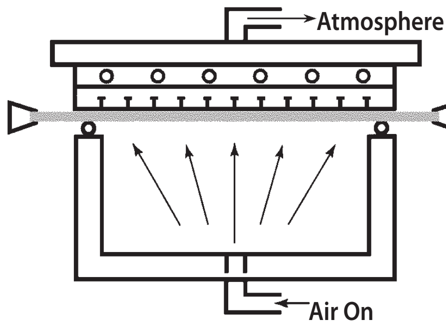
This process is similar to straight vacuum forming except that both air pressure and a vacuum assist are used to force the PALGLAZE SHEET into a female mold. Figures 13A, 13B, 13C, and 13D show the steps in the process.

Figures 13A, 13B, 13C, and 13D. Trapped-sheet contact-heat pressure forming

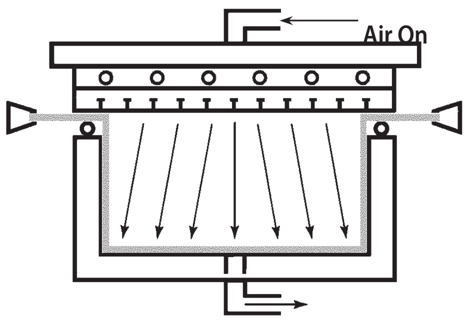
A. A flat, porous plate allows air to be blown through its face.



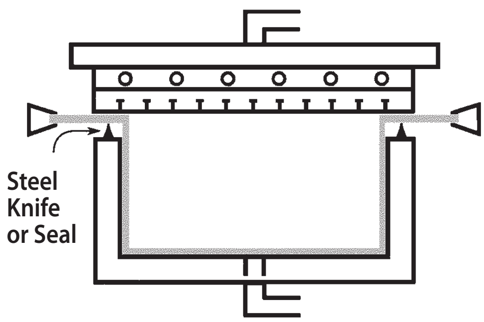
B. Air pressure from below and a vacuum above force the sheet tightly against the heated plate.



C. Air is blown through the plate to force the plastic into the mold cavity.



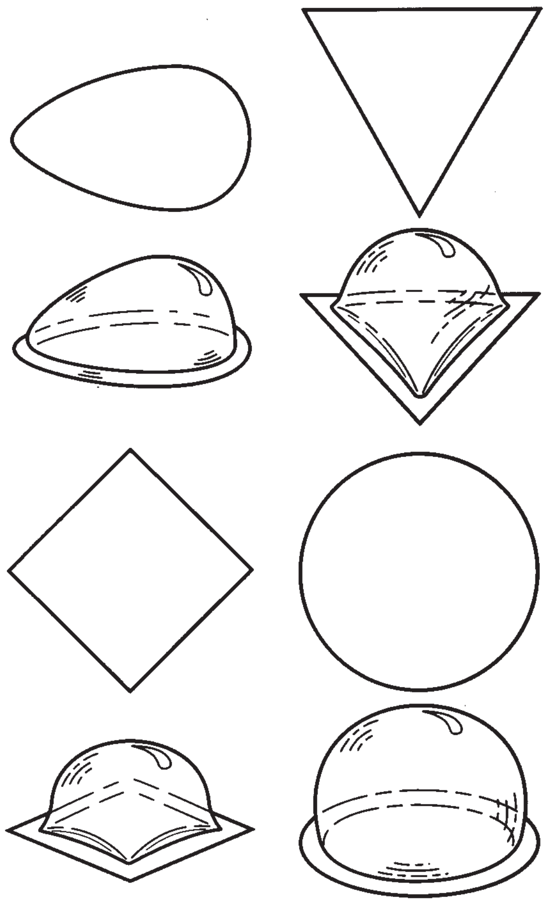
D. After forming, additional pressure may be exerted. Steel knife can be used for seal and subsequent trim if additional pressure is exerted at this stage.



14. Free Forming

In free forming, air pressure of about 2.76 MPa (400 psi) can be used to blow a hot PALGLAZE SHEET through the silhouette of a female mold. Air pressure causes the sheet to form a smooth bubble-shaped article such as used in skylight panels or window well covers. Since only air touches each side of the part, there will be no mark-off unless a stop is used to form a special contour in the bubble. See Figure 14.

Figure 14.



Examples of free-form shapes that can be obtained with openings.

15. Mechanical Forming

In mechanical forming, neither vacuum nor air pressure is used to form a part. The process is similar to match molding, but close fitting molds are not used. Only the mechanical force of bending, stretching, or holding the hot PALGLAZE sheet is used to form the part.

This process can be classed as a fabrication or postforming operation in that a simple wooden jig is used to produce the required shape. Flat stock can be heated and wrapped in cylindrical fashion or possibly bent at a right angle.

D. Assembly

PALGLAZE SHEET can be fabricated into a variety of shapes and articles with solvent, cement (a polymer dissolved in a solvent), or adhesive bonds. In general, when the surfaces to be joined are irregular, a cement is preferred over a solvent.

When PALGLAZE is to be bonded to itself, Palram recommends Acrofix-1218 (See Table 3 below). However, solvents and cements are not the best choice when bonding PALGLAZE SHEET to other thermoplastics. Adhesives, including cyanoacrylics, two-part acrylics, and hot melts, are more effective when bonding PALGLAZE to dissimilar plastics (or to itself). It is worthwhile to invest the time in experimenting with various bonding agents, to determine which performs best in bonding PALGLAZE SHEET to a given different thermoplastic. A given thermoplastic will probably have a unique agent which bonds it best to PALGLAZE. What works well with one, will not necessarily work well with the next.

1. Assembly Guidelines

The following guidelines should be observed when bonding PALGLAZE sheeting:

1 The sheet edges must be clean and free from contamination.
2 The surfaces must be smooth and accurately aligned.
3 A solvent or cement must be sufficiently active to soften the mating surfaces for some flow to occur when pressure is applied.
4 When using solvents in Palglaze sheet assembly, it is advisable that the work area be climate controlled with low humidity to minimize joint "whitening." If this is not possible, the addition of 10 percent glacial acetic acid to the solvent or use of a slower curing, cement-type bond is suggested.
5 Fixture pressure must be maintained to prevent movement of the joint until it is solid.
6 Good ventilation is required when working with solvents. Exposure levels must be controlled to OSHA guidelines.

2. Bonding Techniques: Solvents, Cements, and Adhesives

Small articles with flat surfaces can be joined by placing the pieces together and applying the appropriate bonding agent (solvent, cement, or adhesive). Care should be taken to ensure that the joints are uniformly coated; a solvent can be effectively applied with a needle applicator. The assembly should be clamped into position until the bond is set.

When larger articles are to be solvent bonded, it is best to immerse the joining surfaces in a solvent bath until the material is softened and then clamp them into position until the bond has set. A constant level of solvent immersion should be maintained in a shallow pan with a support pad, screws, and other means to ensure part-to-part uniformity. Table 3 lists several solvents, cements, and adhesives that provide strong bonds with good clarity when used in PALGLAZE fabricating operations.

Table 3 Solvents, Cements, and Adhesives for Palglaze Sheet Fabrication

Material	Bond type
Methyl Ethyl Ketone (MEK)	Solvent
Cyclohexanone	Solvent
Perchloroethylene	Solvent
Methylene Chloride	Solvent
Tetrahydrofuran (THF)	Solvent
Trichloroethylene	Solvent
MECO MR AP/35[a]	Adhesive
MC Bond[b]	Cement
Loctite 408[c]	Cyanoacrylic Adhesive
Perma Bond 910[d]	Cyanoacrylic Adhesive
Perma Bond 268d	Cyanoacrylic Adhesive
Super Glue	Cyanoacrylic Adhesive
Versilok 406[e]	2-Part Acrylic Adhesive
Weld-On 3[f]	Cement
Weld-On 4[f]	Cement
Weld-On 40[f]	2-Part Adhesive
Weld-On 55[f]	2-Part Urethane Adhesive
Union Camp 2690[g]	Polyamide (Hot-Melt) Adhesive
National Starch 34-9002[h]	Reactive Polyurethane (Hot-Melt Adhesive)
Scotch 4950[i]	Double-Coated, Pressure-Sensitive Foam Tape
Scotch 4941[i]	Double-Coated, Pressure-Sensitive Foam Tape
Acrifix 118[j] *(Recommended for bonding PALGLAZE to PALGLAZE)*	Thin-bodied, clear solvent adhesive (1-component)

[a] MECO Gmbh, Postfach 224, D-7753 Allensbach, Germany; Tel: (49) 07533/1611.

[b] Poly Sciences, Inc.,400 Valley Road, Warrington, PA 18976 USA; Tel: 215-343-6484.

[c] Loctite Corp., 999 N. Mountain Rd., Newington, CT 06111 USA; Tel: 203-246-1223.

[d] National Starch Chemical Co., Permabond Division, 480 South Dean St., Englewood, NJ 07631, USA; Tel: 201-567-9494.

[e] Lord Corporation, Industrial Adhesives Division, 2000 W. Grandview Blvd., Erie PA 16509-1098. USA; Tel: 814-868-3611 or Lord Corp. UK Ltd., Stratford Motorway Estate; Barton Dock Rd., Stratford, Manchester, England M32028; Tel: (44) 61-865-8048.

[f] I.P.S., 17109 S. Main St., Gardena, CA 90248 USA; Tel: 213-321-6515.

[g] Union Camp Corp., Chemical Products Div., P.O. Box 60369, Jacksonville, FL 32236 USA; Tel: 904-783-2180.

[h] National Starch and Chemical Co., 10 Fiderne Ave., Bridgewater NJ 08807 USA; Tel: 908-685-5000.

[i] 3M Industrial Specialties Division; 3M Center Bldg., 220-7E-01, St. Paul, MN 55144-1000 USA; Tel: 612-733-1110.

[j] Rohm Gmbh, Kirschenallee, D-64293 Darmstadt, Germany; Tel: (049) 051-18-01.

3. Mechanical Fastening

PALGLAZE SHEET can be fabricated with mechanical fasteners into attractive joints. Self-threading screws are used if the fastener is not to be removed very often. When frequent disassembly is required, threaded metal inserts are preferred.

Screws and rivets provide permanent assembly. Standard nuts, bolts, and machine screws can be used in many instances; In addition, special screws and rivets specifically designed for use with plastics are available. Springs, clips, and nuts are low cost, rapid, mechanical fasteners. Hinges, knobs, catches, and dowels are some other devices used in mechanical assemblies.

The following points should be kept in mind:

Use only aluminum rivets. (Steel rivets may apply too much force causing cracks.)

Always drill a slightly oversized hole to compensate for thermal deflection.

Use neoprene and aluminum washers to distribute the load **(Never use PVC washers! Plasticized PVC is incompatible with PALGLAZE).** Always apply silicone fluid to drilled holes.

Even distribution of metal fasteners avoids excessive accumulation of stress at particular points.

For external use and in locations where the moisture level is high (e.g. shower facilities), **use only rust free materials.**

E. Finishing

1. Sanding

PALGLAZE SHEET is best sanded wet to avoid the frictional heat buildup that is characteristic of dry sanding techniques. If water coolants are used, the abrasive lasts longer and the cutting action is increased. Progressively finer abrasives are used; for example, rough sanding with 80-grit silicon-carbide would be followed by finer sanding with 280-grit silicon-carbide, wet or dry. The final sanding may be with 400- or 600-grit sandpaper. After sanding is finished and the abrasives removed, additional finishing operations may be required.

2. Joining

A standard woodworking jointer-planer will produce accurately aligned and good quality finished edge on PALGLAZE sheeting. Carbide or high speed blades, which have a longer life, will also provide a uniform finish. Since excessive stock removal per pass could result in rough edges, a cut of 0.38 mm (0.015 in.) or less per pass is suggested.

3. Ashing, Buffing, and Polishing

Ashing, buffing, and polishing are accomplished on abrasive-charged wheels made of cloth, leather, or bristles. When a coolant is used, finishing wheel surface speeds of 10.7 to 13.7 m (35-45 ft) per second are suggested; when the wheel is operated dry, lower speeds should be used.

Ashing is a finishing step in which a wet abrasive such as number 00 pumice is applied to a loose muslin wheel. Surface speeds of 19.8 to 21.3 m (65-70 ft) per second are typical since overheating is not a problem in the process.

Buffing is an operation in which a grease- or wax-filled abrasive bar is applied to a rotating muslin wheel. Loose buffs are used for more irregular shapes or for entering crevices. The most common buffing abrasives are tripoli, rouge, or other fine silica.

Polishing, sometimes called luster buffing or brushing, employs wax compounds containing the finest abrasives such as levigated alumina or whiting. Polishing wheels are generally made of loose flannel or chamois. The wax fills many imperfections and protects the polished surface.

4. Filing

When many thermoplastics, including PALGLAZE , are filled, a light powder that tends to clog some files is produced. Therefore, aluminum type A, shear-tooth, or other files that have coarse, single-cut teeth with an angle of 45˚ are preferred. Curved tooth files like those used in auto body shops clear themselves of plastic chips.

5. Flame Polishing and Scratch Removal

PALGLAZE SHEET can be flame-polished using a standard propane torch or a hot-nitrogen welder. Both techniques require accurate control of the distance between the sheet and the heat source; otherwise, surface whitening or excessive material flow may occur. A heat gun such as Model HG 751B, supplied by Master Appliance Corp., Racine, WI, USA, can be used to remove scratches from PALGLAZE SHEET. The hand held unit, which has a temperature range of about 400 ˚C to 540 ˚C (750 ˚F to 1000 ˚F), should be held about 10 cm (4 in.) from the scratch for approximately 5 seconds. The time may vary according to the severity of the scratch.

6. Solvent Polishing

The appearance of saw-cut edges can be improved by first sanding and then solvent polishing with MEK or methylene dichloride. It may be necessary to add a slow drying component such as diacetone alcohol to prevent humidity blush after drying. Complete removal of all surface scratches and edge sand marks is not likely with solvent polishing since PALGLAZE has good chemical resistance.

Note: When using solvents, proper ventilation of the area is essential. Follow all precautions listed on the Medical Safety Data sheet supplied with the solvent being used.

7. Hot Stamping

PALGLAZE SHEET can be decorated by hot stamping such things as letters, designs, and trademarks. The process involves a film of metal or paint on a thin film carrier (usually in roll film) and a hot stamping die. The hot die strikes the surface of the part through the carrier, and the paint or metallic film is fused into the impression made by the stamp. After a short cooling time, a protective lacquer coating is normally applied over the stamped area.

8. Printing

PALGLAZE sheeting can be printed with conventional equipment; however, the ink does not penetrate a plastic as it does with paper and cloth and is therefore subject to damage by abrasion. This can be minimized by applying a light coat of clear lacquer over the printing.

There are a number of different methods used when printing on plastics including letterpress, letterflex, dry offset lithography, rotogravure, stenciling, and a commonly used silk screen process. In silk screening, the ink is forced through a fine metallic or fabric screen onto the product, and a squeegee is used to force the ink through the screen that is blocked off in areas that are not to be printed.

Since each application may require a different type of ink, it is suggested that an ink manufacturer be consulted for recommendations. In general, PALGLAZE SHEET. Eastek Polymers of Eastman Chemical Company supplies a water-based ink that can be used in gravure and flexographic printing applications. Some companies that manufacture inks for use on thermoplastics are listed below.

Naz-Dar Company
1087 N. Northbranch St.
Chicago, IL 60622, USA
Tel: 312-943-8215

Eastman Chemical Company
Eastek Polymers, Valley Brook Center
P.O. Box 1955
Kingsport, TN 37662-5260, USA
Tel: 615-229-2000

Joseph E. Podgor Co., Inc.
7550 Central Hwy.
Pennsauken, NJ 01890, USA
Tel: 609-663-7878

Summit Screen Inks
201 E. 16th Ave.
N. Kansas City, MO 64116, USA
Tel: 816-842-8525

9. Painting

It is possible to paint PALGLAZE SHEET with a variety of painting agents. Two-component paints such as polyurethane or epoxy-based are usually compatible. We suggest that solvent-based paints be avoided, as most solvents and thinners may damage PALGLAZE. If, however, very rapid drying is possible and all residues of the thinner evaporate immediately, it is possible to use standard printing or silk screen equipment and paints. Most paint suppliers have standard paints which are compatible with PALGLAZE. In case of doubt, a compatibility test of a specific paint with PALGLAZE can be performed in our laboratory.

10. Cleaning

PALGLAZE can be cleaned with a soft cloth or sponge, using a mild soap or detergent. Do not scrub or use brushes or squeegees. Rinse and dry with a soft cloth or moist cellulose sponge to prevent water spotting. Where available, a waxy cleaning agent like Mr. Sheen™ is recommended.

F. Chemical Resistance

The effect of chemicals and reagents on PETG, the material from which PALGLAZE SHEET is fabricated, is depicted in Table 4 below. To obtain the data, sections of unstressed 3.2 mm (1/8 in.) bars were prepared. They were weighed and measured. They were then immersed in the chemical or reagent shown and stored at 23 ˚C (73 ˚F) for a period of one year. At the end of the test period, each sample was removed from the jar in which it was tested, wiped dry, and quickly weighed and measured again. The % increase in weight and thickness was calculated. The appearance of the sample after exposure was also recorded.

Ordinarily a plastic would not be suggested for continuous immersion in a reagent that causes an increase of 5% or more in weight or thickness. This does not imply that a change in weight and thickness of less than 5% necessarily indicates the suitability for immersion.

The results of these tests indicate that PALGLAZE is resistant to a variety of chemicals, including ethyl alcohol, high-molecular-weight esters, aliphatic hydrocarbons, and dilute solutions of acids and salts, but was significantly affected by a number of other chemicals and reagents. If PALGLAZE were to be exposed to chemicals at higher temperatures than those used in these tests, the results could be significantly different from those reported here. Therefore, users of PALGLAZE should make and be guided by their own tests equivalent to or representative of those to which the plastic will be subjected in service. Feel free to consult our Technology Department about any chemical exposure that is not covered in the table and unique to your requirements.

Table 4 Chemical Resistance

Reagent	% Change*		Appearance of Plastic After Exposure
	Weight	Thickness	
Acetic Acid, 5%	<1	<1	Very slight yellowing
Acetic Acid, conc.	19	18	Discolored, swollen
Acetone	16	23	Discolored (brown), swollen, rubber-like
Ammonium Hydroxide, conc.	-29	-20	Turned white, outside crumbling off
Ammonium Hydroxide, 10%	4	4	Discolored (pink), outside has blisters
Antifreeze, Automotive Ethylene Glycol Type	<1	<1	No change
Benzene	34	43	Discolored, rubber-like
Bis (2-Ethylnexyl) Phthalate	<1	<1	Very slight yellowing
Brake Fluid, DOT3 (USA)	2	2	No change
Brake Fluid	6	6	Surface attacked, flaking off, turned yellow
Carbon Tetrachloride	27	18	Discolored, swollen
Chromic Acid, 40%	<1	<1	Slightly discolored
Citric Acid, 10%	<1	<1	Slight yellowing
Cottonseed Oil	<1	<1	Very slight yellowing
Deionized Water	<1	<1	Slight yellowing
Detergent, Alconox (0.25%)	<1	<1	Slight yellowing
Dibutyl Sebacate	<1	<1	Slight yellowing
Diesel Fuel	<1	2	Discolored
Dimethyl Formamide	22	39	Badly discolored and distorted
Ethanol, 50%	<1	<1	Slight yellowing
Ethanol, 100%	<1	<1	Very slight yellowing
Ethyl Acetate	20	24	Badly discolored and swollen, softened
Ethylen Dichloride	–	–	Completely deteriorated in one week
Gasohol, 10% Ethanol	9	8	Cloudy, slight yellowing
Gasohol, 10% Methanol	11	10	Cloudy, yellowed
Gasoline, Base for Gasohol	6	6	Slight yellowing
Gasoline	2	3	Discolored
Grease, Automotive	<1	<1	No change
Hand Cleaner, Waterless *Jergens SBS30*	<1	2	No Change
Hexane	<1	<1	Slight Yellowing
Hydrochloric Acid, conc.	1	<1	Badly discolored, blisters under surface
Hydrochloric Acid, 10%	<1	<1	Slight yellowing
Hydrogen Peroxide, 3%	<1	<1	Slight yellowing
Hydrogen Peroxide, 28%	<1	<1	Slight yellowing
Isooctane	<1	<1	Very slight yellowing
Kerosene	<1	<1	Very slight yellowing
Lacquer Thinner	7	6	Cloudy, white

Reagent	% Change*		Appearance of Plastic After Exposure
	Weight	Thickness	
Methyl Alcohol	<1	<1	Very slight yellowing, crazing
Mineral Oil	<1	<1	Very slight yellowing
Motor Oil	<1	<1	No Change
Nitric Acid, conc.	–	–	Completely deteriorated after one week
Nitric Acid, 40%	1	<1	Turned white
Nitric Acid, 10%	<1	<1	Slight yellowing
Oleic Acid, 83%	<1	<1	Slight yellowing
Olive Oil	<1	<1	Slight yellowing
Penetrating Oil, Liquid Wrench #1	10	11	Discolored
Phenol, 5%	13	14	Turned black
Silicone Spray Lubricant	67	34	White, swelled
Soap Solution, 1%	<1	<1	Slight yellowing
Sodium Carbonate, 2%	<1	<1	Slight yellowing
Sodium Carbonate, 20%	<1	<1	Slight yellowing
Sodium Chloride, 10%	<1	<1	Slight yellowing
Sodium Hydroxide, 1%	<1	<1	Slight yellowing
Sodium Hydroxide, 10%	<1	<1	Slight yellowing
Sodium Hypochlorite, 3.5%	<1	<1	Slight yellowing
Sulfuric Acid, conc.	–	–	Completely deteriorated in one week
Sulfuric Acid, 30%	<1	<1	Slight yellowing
Sulfuric Acid, 3%	<1	<1	Slight yellowing
Tapping Oil	<1	1	No Change
Toluene	26	31	Turned white, softened
Transformer Oil	<1	<1	Slight yellowing
Transmission Fluid, Auto	<1	<1	No change
Turpentine	<1	<1	Slight yellowing

*Changes shown are increases unless the figure is preceded by a negative sign.

A p e n n d i x

Typical Physical Properties of PALGLAZE Sheet (3 mm = 0.12 in.)

Property	Type	Conditions (U.S. Customary)[a]	ASTM Method[b]	Units - SI (U.S. Customary)[a]	Value (U.S. Customary)[a]
Density	Physical		D-1505	g/cm³ (lb/ft³)	1.27 (79)
Water Absorption	Physical	24 hr. @ 23 °C	D-570	%	0.13
Tensile strength at yield	Mechanical	50 mm/min (2 in./min)	D-638	MPa (psi)	50 (7,300)
Tensile strength at break	Mechanical	50 mm/min (2 in./min)	D-638	MPa (psi)	24 (3,500)
Elongation at yield	Mechanical	50 mm/min (2 in./min)	D-638	%	5
Elongation at break	Mechanical	50 mm/min (2 in./min)	D-638	%	230
Tensile Modulus of Elasticity	Mechanical	1 mm/min (0.04 in./min)	D-638	MPa (psi)	1,300 ($1.9x10^5$)
Flexural Modulus	Mechanical	1.3 mm/min (0.052 in./min)	D-790	MPa (psi)	2,050 ($3.0x10^5$)
Flexural Strength at Yield	Mechanical	1.3 mm/min (0.052 in./min)	D-790	MPa (psi)	77 (11,200)
Izod Impact Strength Notched (23 °C)	Mechanical		MD-256	J/m (ft·lbf/in.)	120 (2.2)
Impact Strength Charpy Notch (23 °C)	Mechanical		D-256	J/m (ft·lbf/in.)	140 (2.6)
Impact Falling Weight	Mechanical		Palram[b]	J (ft·lbf)	85 (63)
Rockwell Hardness	Mechanical		D-785	R scale	113
Heat Deflection Temperature	Thermal	Load: 1.82 MPa (264 psi)	D-648	°C (°F)	70 (157)
Vicat Softening Temperature	Thermal	Load: 1 kg (2.2 lb)	D-1525	°C (°F)	83 (181)
Coefficient of Linear Thermal Expansion	Thermal		D-696	10^{-5}/°C (10^{-5}/°F)	6.8 (3.8)
Thermal Conductivity	Thermal		C-177	W/m K (Btu·in/hr·ft^{2}·°F)	0.19 (1.3)
Specific Heat Capacity	Thermal		C-351	kJ/kg K (Btu/lb°F)	1.3 (0.31)
Haze	Optical		D-1003	%	<1
Light Transmission	Optical	P.E. Lambda 6	D-1003	%	89
Refractive Index	Optical		D-542		1.57
Yellowness Index	Optical	Spectrophotometer	D-1003		<1.5
Dielectric Constant	Electrical	1 kHz 1 MHz	D-150 D-150		2.6 2.4
Dissipation Factor	Electrical	1 kHz 1 MHz	D-150 D-150		0.005 0.02
Dielectric Strength Short Time	Electrical	500 V/s	D-149	kV/mm (V/mil)	20.3 (520)
Surface Resistance	Electrical	Ketley	D-257	Ohm	$4.1x10^{15}$
Volume Resistance	Electrical		D-257	Ohm-cm	$1.7x10^{17}$

[a] Conditions, units and values in U.S. customary units are presented in the table within parentheses.

[b] All the results depicted in this table were obtained by following the indicated ASTM method except where another method is indicated by the appearance of this symbol ([b]).

Appendix 2

Appendix 2. Special Considerations when Thermoforming PALGLAZE UV

When thermoforming PALGLAZE UV, a white haze in the form of streaks may appear on the UV side, particularly in deep drawing. This phenomenon is presumably a thermal effect of the additives in the UV layer.

There are two alternatives to eliminate this problem:
1. It is preferred that PALGLAZE UV be thermoformed with the polyethylene (PE) masking on the sheet. Leaving the PE masking on the UV side is sufficient, but there is no reason not to leave it on both sides. Leaving the PE masking in place will not only eliminate the white haze, but also will improve the surface appearance of the product in general. The PE masking is designed for thermoforming and should peel off quite easily after the sheet cools.
2. If it is necessary to remove the PE masking, flame or hot air polishing is very effective in eradicating the white haze. It was found also that hot air polishing is very effective at hiding and smoothing out any surface pitting and marks from dust or from mold contact. Using a commercial hot air gun (*e.g.* "Liester") at its highest set point for very rapid and effective polishing is recommended. The gun should be passed over the product using parallel, smooth, rapid strokes. Working in this manner will avoid a heat buildup which could cause warping and eventual melting of the sheet or product. Using a lower air temperature will require moving the gun more slowly. This also could result in overheating and warping.

The following operating conditions are suggested:
1. Air temperature at the nozzle: Approximately 600 °C.
2. Treatment speed: 2-3 cm/sec.
3. Nozzle distance from the sheet surface: 20 - 30 mm.
4. Angle of nozzle with respect to sheet surface: 60° - 90°.
5. It is preferable to move in straight parallel lines, not in circles, to let the surface cool down before treating the adjacent areas.
6. The result of following these instructions will be polished areas of 30 - 40 mm width with a highly glossy appearance.

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