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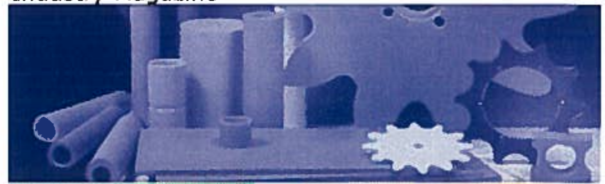
THE PLASTICS Distributor & Fabricator YOUR INDUSTRY MAGAZINE



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Category: Miscellaneous

Volume: 20
Issue: 5
Article No.: 2260

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THERMOFORMING ACRYLIC SHEET

Acrylic sheet can be thermoformed using several types of equipment such as vacuum, pressure, or stretching equipment, and a variety of heating methods including coiled nichrome wire, metal (cal) rod, hot air ovens, ceramic elements, and quartz tube (nichrome filament and tungsten filament). These heat sources derive average life spans ranging from 1,500 to 20,000 hours at varied efficiency levels.

The following is offered as a resource for thermoforming equipment and procedures. Users should undertake sufficient verification and testing to determine the suitability for their own particular purpose.

HEATING METHODS

Vertical Ovens

Forced circulating-air ovens heat uniformly at consistent temperatures and are commercially available. These ovens consist of an outer and inner shell separated by a space containing fiber or rockwood insulation. Inside, the ovens have thermostatically controlled heaters. Baffles and electric fans can also be used to ensure even heat distribution. Because of its relatively low molecular weight, acrylic sheet cannot be hung from a single edge. A clamping frame should be used for support and to facilitate sheet transfer to the forming station. Before heating with an air oven, be sure that you can reliably control temperature thermostatically within 10 °F (5°C) between 340-350°F; air velocities across the sheet range between 200-1000 feet per minute (1-5 m/s); temperatures throughout the oven are uniform; and the clamping frame exerts constant uniform pressure on all sides as the sheet becomes soft.

Horizontal Heaters

Using horizontal infrared heaters (ceramic elements for instance) instead of hot air ovens are faster and less labor intensive. Horizontal units are also more flexible because either the heater or the tooling can be moved. Working clearances can often be improved by moving the heaters, and systems can be designed to handle custom made blanks.

When designing a horizontal heating system, independently controlled zones can be set up to improve control and flexibility.

Thermoforming Machines

Thermoforming machines are ideal when large volumes of the same shape are being produced. However, tooling costs are usually high. Multiple shapes can be formed at the same time from a single sheet. Post machining will be needed to separate and finish the parts.

Vacuum and Pressure-Forming Equipment

Many types and sizes of forming equipment are commercially available. Trade publications dealing with plastics list many equipment manufacturers.

How to Make a Vacuum Chamber

An airtight chamber can be fabricated from welded steel plates. Steel should not be used for the forming plate since it may "chill" the hot sheet. A hardboard forming plate about 1/2 inch in thickness is recommended.

The detachable forming plate can be sealed to a flange on the top of the vacuum box using a gasket. The sheet blank is clamped in place over the forming plate using a clamping or holding ring and several toggle clamps.

The shape of the formed part's base will be determined by the shape of the cutout in the forming plate. Regulating the vacuum between the vacuum chamber and a vacuum storage tank will control the height or depth of the part. Required equipment: a high speed vacuum pump (10 cfm minimum), a vacuum storage tank, a 1" gate valve, a vent valve for releasing vacuum after the part is formed, and a vacuum gauge.

Free-Blowing Equipment

The required equipment for free blowing includes a plywood board with an air hose attached to its underside and a forming plate for controlling the piece's contour at its base. To evenly distribute incoming air, baffle the air intake with foam, felt, or cardboard. Cover the plywood board with flannel or polyurethane foam to prevent mark-off. The forming plate or ring should be made from approximately 1-1/2" thick hardboard. Quick-acting toggle clamps may be used to attach the heated sheet and the ring to the plywood base.

Plug-and-Ring Forming Equipment

Rings or plates can be made from hardboard, plywood, or metal; plugs are usually made from hardwood; and the equipment should be coated with flocked rubber sheet to minimize mark-off. For producing large volumes of parts, durable aluminum rings and plugs can be used.

PROCEDURES

Be sure to follow manufacturers' safety recommendations for equipment and material as various acrylic sheet products react differently when heated to forming temperatures.

Shrinkage

Because of the orientation imparted during manufacture, acrylic sheet shrinks slightly when heated to thermoforming temperatures. Manufacturing direction can be determined from the sheet label or print on the masking. The lines of print are perpendicular to the direction of manufacture.

Original dimensions won't change in fabrication operations not requiring heat. However, sheet heated to thermoforming temperature changes dimensionally by about 3 percent maximum shrinkage in the manufacturing direction and approximately 0.5 percent maximum width increase (transverse direction).

Measure the shrinkage in a preliminary test, if acrylic sheet isn't held in a retaining frame. Then, determine the size of material required to compensate for shrinkage before cutting any blanks.

Predrying

Predrying acrylic sheet is rarely necessary. Keep the sheet wrapped until used. To prevent blistering, dry high-water-content sheet in a forced-circulation drying or vacuum oven before heating. Drying time depends on water content and material thickness. 24 hours at 176°F (80°C) dries most sheets. To reduce the length of the forming cycle, pre-dry the sheet in a spare oven and transfer it directly into the forming oven at 176°F (80°C) after the drying period.

Heating

To avoid blistering or distortion, heat the sheet to the low end of the forming temperature range using convection, conduction, or radiation heating.

The standard procedure for a vacuum forming machine is to clamp the cold sheet in a frame and heat it by infrared radiation.
Stresses may arise due to the sheet becoming hot while the clamped edges stay cold. Tearing, edge distortion, and asymmetrical shapes may also occur. To avoid these problems, heat the clamping frame to 140-180°F (60-82°C). Clamp the sheet and continue heating.

When using high-intensity quartz tube heating panels, a short soak cycle should be included after the heating cycle and before forming. This results in more even heat distribution across the sheet's thickness.

Forming Temperature

The forming range for acrylic sheet is 290-320°F (142-160°C). Even temperature distribution throughout the sheet's thickness is recommended. Before forming, the sheet's temperature must be higher than the desired temperature to allow for cooling that will occur prior to the start of forming.

Specification of adequate oven temperature makes for easy adjustment and control. In cases like infrared heating, where temperature specification is impossible, find the approximate temperature by using a pyrometer calibrated for plastics. Thermometer papers that show the sheet's surface temperature by a color change can also be used.

Temperature requirements depend on forming conditions - the degree of shaping (stretching) and the forming rate. To prevent pimples, blisters, shading changes, and other damage, avoid higher-than-necessary temperatures. A template or mold can mark overheated material.

Heating Time

Heating time depends on material thickness and heating method. Conditions during heating like air velocity in the oven, panel-to-heater distance, etc. also affect heating time. Final product and surroundings are other factors.

These variables are too numerous to predict mathematically. Minimum heating times should be determined by running test cycles. With some experience, cycles that result in evenly and thoroughly heated sheets can be developed.

Forming Rate

The maximum forming rate of a sheet is limited to the speed at which it will stretch without exceeding its strength and fracturing. The minimum forming rate must be fast enough to prevent the sheet from cooling appreciably. A highly pigmented sheet should be formed slower than a colorless or transparent material.

Excessive fast forming rates will impart high stresses and cause low craze resistance. To minimize stresses, use moderate forming rates and ensure a uniform temperature distribution over the surface of the sheet and across its thickness.

Higher forming temperatures are needed to achieve greater "draws" or increased definition. For a "slow" forming operation it may be necessary to continue with infrared heating while the part is being formed.

FORMING PROCESSES

Drape Forming

Here, acrylic sheet is heated and bent over a positive (male) or into a negative (female) mold. Female molds are best because they compensate for sheet shrinkage during cooling and sheet "memory." To deter mark-off, cover the molds with rubberized flocking or billiard table felt. For the same reason, set mold temperature high and forming temperature low.

Cover the surface so the cooling rate is the same on both sides of the mold (thick cloth or felt blankets make good covers). If the mold and blanks are larger than the finished part, trim off clamping frame marks.

Form compound contoured parts like those used for bus rear windows and roof glazing. After heating to the formed temperature, gently position and clamp the sheet over a positive mold with the shape of the finished part's external contours.

Free Blowing and Vacuum Molding

Many configurations can be free blown using a shaped clamping ring or vacuum-drawn using a mold box. Items of high optical quality can be produced by these methods because the surface of the material never touches the mold walls. Thus, no mark-off or local cooling occurs.

A variety of spherical surface shapes can be molded depending on the geometry of the clamping frame when using these techniques.

The pressure or vacuum is varied to get the desired height or depth. The height is demarcated with a jig or soft material designed to avoid marking. Pressure or vacuum can also be controlled automatically with optical light sensors. Although this method is expensive, its lack of contact creates an advantage in optical-critical production.

A simple suction or blowing mold consists of a base plate with a clamping frame. A sufficient amount of mechanical or hydraulic toggle clamps must be provided to maintain frame rigidity and to withstand the forming pressure. Using screw clamps has the disadvantage of being time consuming and may allow the sheet to cool excessively before it is formed. Beaded clamping frames will seal better than flat frames.

For free blowing, use up to 75 psi of air pressure. Provide large air connections so that large parts can be shaped quickly. Be sure that incoming compressed air does not hit the hot panels directly and cause local cooling. Installing baffles or screens in front of the inlet opening can deflect the incoming air.

Resting the sheet blank on a cold base plate may cause undesired cooling while installing the clamping frame. To reduce this, heat the plate or cover it with thick, non-linting cloth.

Vacuum forming requires the same fundamental conditions as pressure forming except that less clamping force is needed because suction seals the sheet to the vacuum box virtually automatically and the pressure difference is limited to 15 psi or less. If possible, arrange the suction ducts in a ring around the edge of the vacuum box to prevent airflow from cooling only one side of the part. For processing large parts, fit a reservoir (or vacuum tank) in front of the vacuum pump for quick evacuation of large volumes of air.

Vacuum with Plug Assist in Negative Mold

Essentially the same considerations apply here, as with blowing, except that the smaller available pressure difference -- one atmosphere -- limits this technique's application to simple moldings without strongly undercut portions.

Vacuum to a Positive Mold with Mechanical Pre-stretching

By comparison with combined processes using negative molds, sucking onto a positive mold has the advantage that the mold becomes the pre-stretching plug. Also, marks may appear on only one surface.

Where vacuum provides insufficient force, compressed air may be used. In either case, the mold should be heated and suction or venting holes must be provided at its extreme points.

Plug and Ring Forming

Use this method for trays, sign faces, lighting fixture diffusers, or any part not deep-drawn for which mark-off at the inside corners is acceptable. The mold includes a forming plate, clamping plate, and a male plug.

The molded part's outside contour conforms to the forming plate, but its opening is larger. To provide a sheet's thickness clearance between the male and female mold parts, the slightly tapered male plug is smaller than the forming plate's inside dimension.

The mold can be set up in an air cylinder press or in an arbor or drill press for small parts. Position the heated sheet on the forming plate and hold it using the clamping plate (toggle clamps or C-clamps can be used to hold the forming and clamping plates together). The male plug is forced through the clamping and forming rings to a predetermined depth.

Vacuum Snap-Back Forming

Free blowing and vacuum forming produce natural "surface tension" shapes or bubbles which a forming plate can control only at the base. Vacuum snap-back forming employs a male plug attached to an air cylinder's ram. The plug is lowered into the vacuum-formed bubble. This method combines plug-and-ring and vacuum forming. Drawing vacuum on a hot sheet forms a bubble. A male plug is positioned inside the bubble. Gradually, vacuum pressure is released and the hot sheet, because of its "elastic memory," snaps back and clings to the male plug.

The plug, frequently of hardwood, should include a 2^{o} to 3^{o} taper (draft), easing removal after cooling and contraction as well as vent holes to avoid trapping air at the bottom surface. This method enables production of irregular shapes, with the forming plate's cutout and the male plug's shape controlling the contour.

Cooling

After forming, cool the parts to below 140-160 F (60-70 C). Don't just cool the surface -- the interior must also cool. Provide uniform cooling on all sides to prevent stress. Completely cover slow cooling thick-walled parts with felt or blankets to block drafts.

There's no rule of thumb for predicting sheet interior's cooling time. Factors include material thickness, ambient air temperature, and airflow to the part. Experience is the best teacher.

As it cools, the sheet shrinks to reverse heat-caused expansion. Allow it to move freely to prevent stress. Shrinkage on the mold can also cause stress, it is best to remove the part as soon as it achieves dimensional stability.

PROBLEM	CAUSE	SOLUTION
Uneven Shapes	Uneven heating temperature Clamping frame not hot	Be sure all heaters are functioning. Eliminate drafts. Baffle heat on all sides.
Bubbles	Heating too rapidly	Lower temperature. Increase distance between heaters

	Uneven Heating	and sheet Be sure all heaters are functioning. Use screening to balance heat.
	Excess moisture	Predry. Preheat. Keep masking on sheet until formed. Use older material first.
Surface markings	Improper mold surface Dirt on sheet	Use proper mold covering (foam, felt, flocking). Clean with deionized air.
Uneven Edges	Excessive forming temperature differental	Preheat clamping frame. Use slip clamp frame (low/high)
Raised Corners	Excessive Stress	Heat frames to proper temperature before inserting sheet. Add supplemental heat to corners.
Cracking in corners	Stress concentration	Heat sheet evenly. Preheat frames or use heated frames. Add supplemental heat to corners.

NOTE: Acrylic sheet is a combustible thermoplastic. Precautions should be taken to protect this material from flames and high heat sources. If not extinguished, acrylic sheet will burn rapidly to completion. The products of combustion, if sufficient air is present, are carbon dioxide and water. However, in many fires sufficient air will not be available and toxic carbon monoxide will be formed, as it will when other common combustible materials are burned. Good judgement is urged in the use of acrylic sheet. It is recommended that building codes be followed carefully to assure proper use.

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