PLASKOLITE

OPTIX® XL & OPTIX® XTRA ACRYLIC SHEET

THERMOFORMING GUIDE

CONTENTS

SUMMARY TEMPERATURE GUIDE TO THERMOFORMING OPTIX XL AND OPTIX XTRA

TOP AND BOTTOM HEATED THERMOFORMER, ˚F

PRODUCT	TOP TEMPERATURE			BOTTOM TEMPERATURE		LOW ZONING OR SCREENING	
	TARGET	MIN	MAX	TOP	BOTTOM	TOP	BOTTOM
ALL PROUCT EXCEPT GRANITES	400-410	390	420	360	410	330	320
GRANITES	380-390	370	390	340	390	330	320

TOP HEAT ONLY THERMOFORMER

PRODUCT	TOP TEMPERATURE			BOTTOM TEMPERATURE	LOW ZONING OR SCREENING	
	TARGET	MIN	MAX	TYPICAL	TOP	BOTTOM
ALL PROUCT EXCEPT GRANITES	400-410	390	420	280-360	330	270
GRANITES	380-390	370	390	280-360	330	270

XTRA – TOP AND BOTTOM HEAT, ˚F

PRODUCT	TOP TEMPERATURE			BOTTOM TEMPERATURE		LOW ZONING OR SCREENING	
	TARGET	MIN	MAX	TOP	BOTTOM	TOP	BOTTOM
ALL PROUCT EXCEPT GRANITES	400-410	390	420	300	360	330	290
GRANITES	380-390	370	390	300	360	330	290

HEAT CYCLE TIME

The best determination of when to pull the sheet out of the oven is using an IR sensor in the center of the oven. After the initial set-up this will give very reproducible results sheet after sheet. The next best method would be through using an IR thermometer to measure the bottom sheet temperature. Not as reliable, is heating the sheet to a consistent time. The oven time technique can be combined with the use of an IR thermometer or hitting the bottom of the sheet to check its flexibility.

THERMOLABELS

Thermolabels should be used to verify the performance of the oven and to assure the sheet is not being over or insufficiently heated. If the sheet is not heated enough, you usually can tell by the loss of detail in your part. Overheating the sheet can lead to blisters.

HEAT SOAK*

The information contained in this guide was done without using heat soak method. This is the practice of holding the sheet at a temperature for a specified time. The purpose of this practice is to ensure the sheet has reached uniform temperature. All the information contained in this guide was done without using heat soak. Using heat soak can increase the possibility of getting blisters or getting "orange peel" in thinner drawn portions. In most cases heat soak is not required and should not be used for Granites or XTRA.

*The information contained in this guide was done without using heat soak method.

TYPE OVEN: EFFECT OF THERMOFORMING OVEN, TOP ONLY OR TOP AND BOTTOM OVEN

Where the heat is generated from makes a difference in how the material performs. For products 125 mil and thinner, you can use ovens that heat from just the top, but realize that depending upon the oven enclosure, environment or wind coming through a large opening, the bottom temperature will be less controlled. Here's data on how the intensity of the heat and the design of the oven affects the resulting heat cycle time and temperatures. Note, how for 187 mil sheet, heating with just the top oven and increasing the heat intensity results in a lower bottom temperature when pulled at the same top temperature of 410˚F. Turning up the heat has a "broil" affect. Not so with 125 mil sheet.

OPTIX XL 125	HEATER SEATING	TOP TEMP ˚F	BOTTOM TEMP	AVERAGE TEMP	CYCLE TIME	AVERAGE RADIUS (MM)
TOP HEAT ONLY	80/0	410	340	375	4:05	6.5
	90/0	410	330	370	3:08	6.6
	100/0	410	330	370	3:13	6.4
TOP AND BOTTOM HEAT	80/50	410	355	383	3:22	6.0
	90/60	410	360	385	2:04	6.4
	100/70	410	370	390	1:44	6.1

OPTIX XL 187	HEATER SEATING	TOP TEMP ˚F	BOTTOM TEMP	AVERAGE TEMP	CYCLE TIME	AVERAGE RADIUS (MM)
TOP HEAT ONLY	80/0	410	290	350	4:58	9.9
	90/0	410	280	345	3:53	10.8
	100/0	410	270	340	3:43	11.5
TOP AND BOTTOM HEAT	80/50	410	320	365	4:24	8.6
	90/60	410	330	370	2:54	9.6
	100/70	410	365	387.5	2:48	7.5

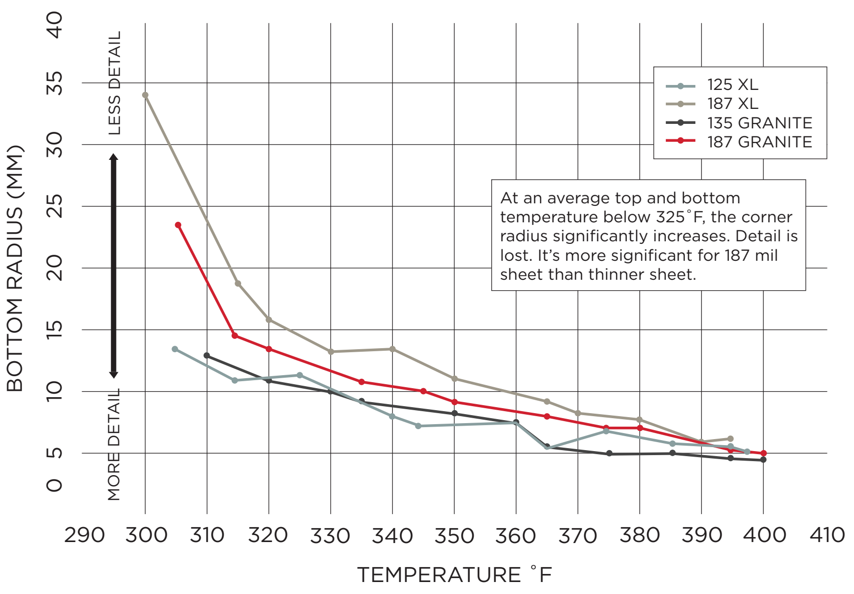
The heat setting and cycle time is dependent on the controls and type of oven. The sheet distance from the heater elements also has an effect. The zone settings and heat cycle times above only apply to the R&D thermoformer in the PLASKOLITE lab. However, the same general principles apply to your thermoforming oven.

*Please conduct trials with your equipment for verified results

TEMPERATURE: EFFECT OF TEMPERATURE ON PART DETAIL

With top and bottom heat ovens on, 125, 135 and 187 mil sheet were heated and vacuumed formed and the result of the bottom radius was measured. The table below shows that specific temperature details are lost (the bottom radius increased significantly) more so for thicker sheet. Each oven and molds are different and the temperature must be fine tuned to ensure the resulting detail and thickness meets the needs.

125, 135, & 187 MIL SHEET BOTTOM RADIUS VS. TEMPERATURE

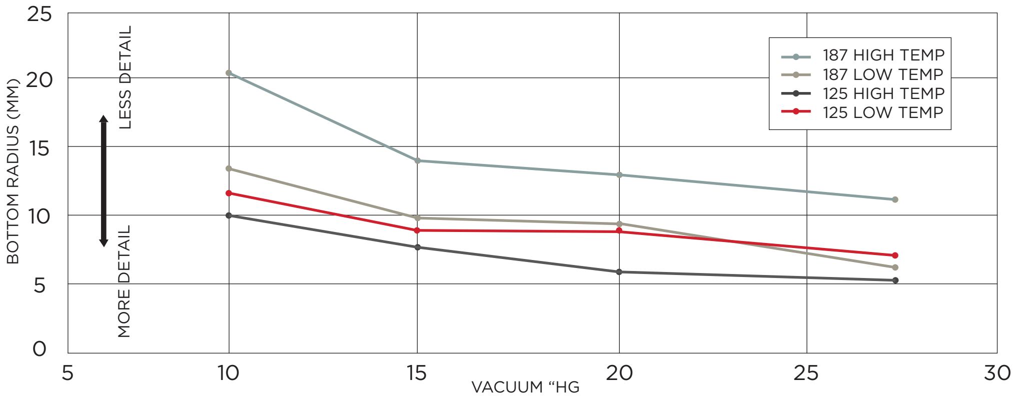


LOW TEMPERATURE ZONING AND SCREENING

Low temperature zoning and screening are the application of reduced heat in a specific area. This will cause other areas to stretch more but will also reduce the heat that is low zoned or screened. As temperature is reduced, corner radius also gets larger and the part gets thicker in the area that's low zoned or screened. It is an effective way of thickening areas that are coming out too thin. Typically, several trials need to be run to determine proper outcome (part detail, corner thickness) from using these techniques.

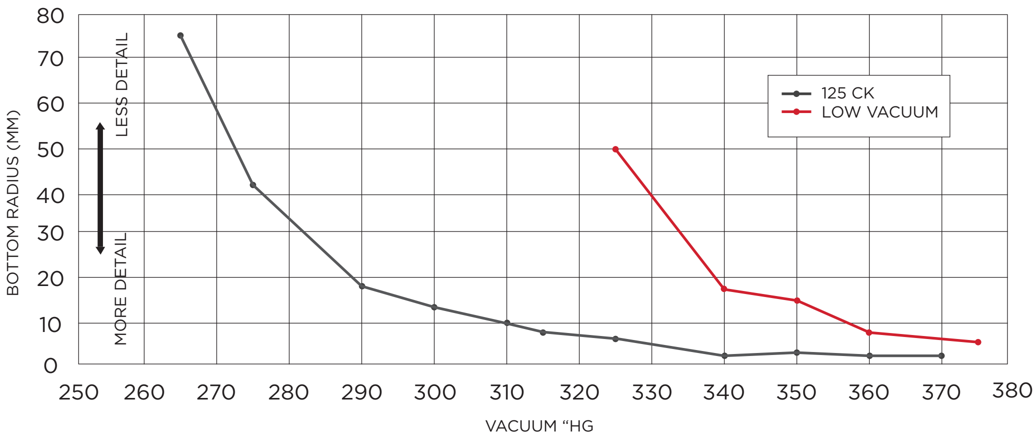
VACUUM: EFFECT OF VACUUM ON PART DETAIL

Vacuum can affect the amount of detail realized from OPTIX Acrylic. Vacuum tanks should be sized to deliver the amount of vacuum needed throughout the forming process. Rule of thumb, the volume of the tank(s) should be 4 times the volume of the largest mold. In the graph below, various levels of vacuum were used to thermoform 125 and 187 mil sheet and the resulting corner radius was measured to illustrate the affect of vacuum on detail.



Vacuum flow rate can affect the amount of detail in the part. Here is an extreme example of how vacuum flow rate can affect the amount of detail in the part. Full 27" Hg vacuum was applied, one had super low vacuum flow rate while the other had very high vacuum flow rate.

HIGH VACUUM FLOW RATE VS LOW VACUUM FLOW RATE



VACUUM TIME & SHEET COOLING OUT OF THE OVEN

In most thermoforming setups, the sheet is taken out of the oven to meet the mold. During this process, the sheet is cooling. Thinner sheet cools down faster than thicker sheet, so the time it takes for the sheet to meet the mold surface becomes critical to having good part definition. In addition, as the sheet is going to the deeper mold sections, it's getting thinner and there-by cooling quicker. The longer it takes the sheet to meet the mold surface, the more it's necessary to heat the sheet to compensate for this heat loss if the desired detail is not achieved.

The time out of the oven can be broken up into two parts:

· The time it takes the sheet to get out of the oven and lock-on to the mold.

· The time it takes the sheet to reach the bottom mold surface.

AVERAGE TIME (seconds)	**SPAS**	**BATH**
CLAMP FRAME TO MOLD/SHEET LOCK	9	14
SHEET TO MOLD SURFACE	34	12
TOTAL TIME	42	26

Rather than heating up the sheet more to compensate for this heat loss, if the vacuum time is excessive, try to decrease the vacuum time by:

· increasing the amount of available vacuum

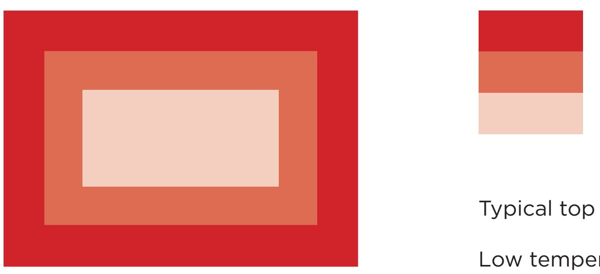
· decreasing the amount of leaks

· increasing the vacuum line size (increasing the vacuum flow)

· decreasing the number of restrictions in the vacuum line

ZONING: TEMPERATURE CONTROL AND SCREENING

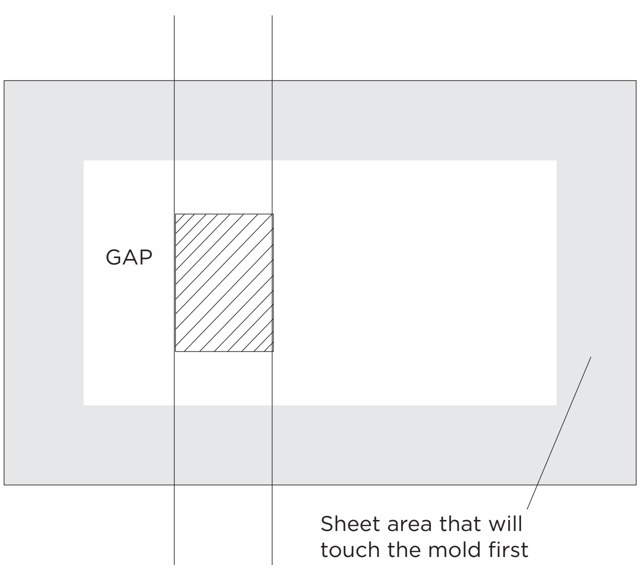
Zone settings are typically set up with the hottest zones on the perimeter. This is where the majority of the heat loss takes place due to the location being close to the edge of the oven and the heat loss due to the clamps. The top oven is typically 14-16" away from the sheet, while the bottom oven (if it's a dual oven thermoformer), 36 to 40" away. The bottom oven has to be further away from the sheet to prevent the sheet from touching the elements as it sags upon heating. With the bottom oven being further away from the sheet, it should be set slightly higher than the top oven. This can be fine tuned using thermolabels on the top and bottom oven. It also depends on what elements are used for the top and bottom oven if they are not the same.



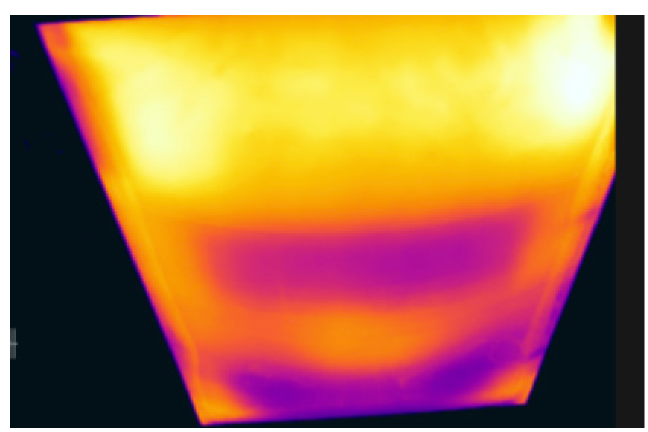
Typical top and bottom zone setup.

Low temperature Zoning and screening

If the thermoformer has multiple zones 12" x 12" or less, then it's possible to do do temperature "screening" using zone settings. If not, the best way to do screening is by using actual screens. With multiple zones it may be easier to keep up with screeens instead of having multiple recipes stored in the operating panel for each mold. The screens can be purchased at the hardware store and should be made of aluminum, not plastic screen material. The placement of the screens goes between the acrylic and the top heat elements. Multiple screens can be used to achieve the temperature reduction desired. Screens should be kept as small as possible, sufficient to cover the area you want to come out a little thicker. The areas on either side of the screen should not touch the mold first. This is shown in the following diagram.



Thermal Image of sheet with screens placed to reduce the heat in specific areas of the sheet.



CLEANING

Carefully cleaned sheets and molds will minimize irregularities and blemishes and ensure production of a smooth, glossy part. However, acrylic sheet usually carries a static charge and attracts airborne dust, saw chips, and dirt. The best way to control this is to maintain a very clean thermoforming area and try to isolate dirt and dust from the spray-up and hole drilling areas. The acrylic sheet may be cleaned effectively with a diluted solution of isopropyl alcohol. That method has the advantage of reducing static and removal of small particles and fibers. Any fibers on the sheet, especially blue jean fiber, can leach colored dye to the sheet at thermoforming temperatures.

Potentially faster, a common method of cleaning is to use an ionized air gun which tends to reduce static charge buildup versus non-ionized air, as it blows contaminants off the sheet. Numerous other static eliminating cleaning agents exist, but none of these methods is more effective than a scrupulously clean thermoforming area.

It's important to clean the mold surface prior to vacuum forming. The most effective way is by use of a vacuum cleaner vacuuming out the mold followed by the use of tack cloth to get any remaining fine particles. The tack cloth is also useful in cleaning sheets.

Tack cloth to clean sheets and molds.

MASKING: EFFECT OF TEMPERATURE ON MASKING

Masking adhesion is directly affected by thermoforming temperatures. Utilizing normal temperatures and heat cycle times and the masking comes off easily. Too much heat or extra-long heat cycle times will result in the masking coming off in strips or being extra hard to remove. In fact, when the masking comes off in strips is a clear indication that the sheet was overheated in the thermoformer.

To understand how the masking works, several samples were prepared ahead of time demonstrating how thermoforming temperatures affects masking adhesion. At normal thermoforming temperatures the masking is easy to remove and comes off in one piece. As the thermoforming temperature increases above recommended thermoforming temperatures, the masking adhesion goes up significantly. Thermoforming temperatures should be kept at or below 420 °F to be able to remove masking easily.

The best way to tell if the top surface of the sheet is being overheated is with the use of thermolabels. Please see hyperlink to technical bulletins on how to use thermolabels.

Samples were prepared at various temperatures and the masking adhesion measured. This was the data collected:

THERMOFORMING TEMPERATURES AFFECT ON MASKING ADHESION

PIECE	PEEL STRENGTH (gms/inch)	COMMENTS
NO HEAT	26	EASY TO PULL OFF
400	80	EASY TO PULL OFF
410	65	EASY TO PULL OFF
420	75	EASY TO PULL OFF
440	170	(VARIABLE)
450	175	(VARIABLE, MASKING BROKE IN THE 1 INCH PULL TEST)

The comments in the above table were observed when the sample strip was pulled by hand.

This table indicates above 420˚F the masking begins to adhere to the acrylic making it almost impossible to remove the masking in one sheet, but breaks off in strips. At certain points it adheres so much the masking breaks off in strips. To avoid this happening the top surface temperature should be kept at or below 420°F. Use thermolabels to verify sheet temperatures.

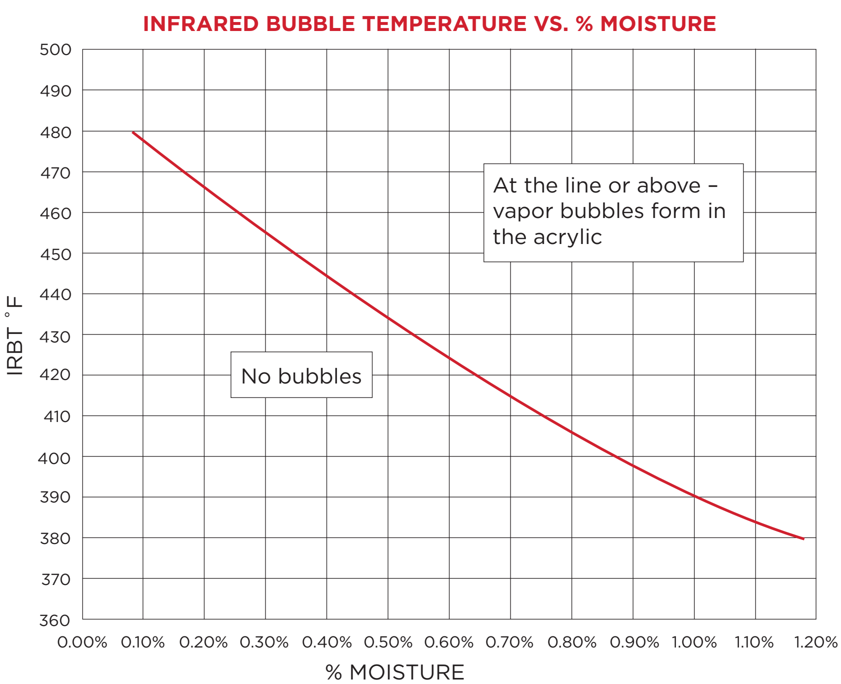
For 187 mil sheet and top oven only heating, its standard that the thermoforming time is increased to try to improve the resulting detail. Heating times greater than 8 minutes, even if the temperature is kept under 420°F, can also result in the degradation of the masking due to heat.

BLISTERS: EFFECT OF MOISTURE ABSORPTION

Moisture absorption can result in blisters, which are vapor pockets in the material, when the sheet is heated. It's important to re-wrap the acrylic after use and perhaps use lower temperatures for the top and bottom sheets.

When acrylic absorbs moisture, the highest temperature that can be used is reduced. Consider the graph below, at 410°F, and 0.5% moisture there will be zero blisters in the acrylic sheet. If the amount of moisture in the sheet goes up to 0.8%, a blister may form. This is without using the technique "Hold Time". An acrylic sheet that doesn't blister at 410°F, can start to blister after being held at that temperature for more than 1 - 3 minutes depending upon moisture level.

Moisture in the sheet is suppressed from forming bubbles due to pressure. However, if enough moisture pressure builds up, a bubble will form. This can happen rapidly with too high of a temperature for % moisture contained in the sheet or slowly from building up pressure from being held at a temperature for a period of time. This concept is easier to understand by watching how bubbles form in water while being heated. Before reaching boiling, the trapped and dissolved gases are constantly forming bubbles as temperature is increased. This can happen in acrylic but at higher temperatures.



STORAGE OF SHEET

All sheets should be stored indoors. Ideally, XTRA, which has an ABS backing, should be stored in a heated dehumidified room.

Acrylic sheet is protected from absorbing excessive moisture by being wrapped in foil. When opening the package, the foil should be opened where it was taped. If all the sheet is not immediately used, the remaining sheets should be recovered with the foil and for further protection, the cardboard it was shipped with.

THERMOFORMING MACHINE

THERMOFORMING MACHINE CONSIDERATIONS

1. Top oven
2. Bottom oven (for products over 187 mil and thicker)
3. Sag eye for safety
4. IR Sensor for heat cycle control
5. Zone control (Coarse vs. fine)
6. Clamp system
7. Clamp frame movement vs. platens
8. Vacuum System and Tank capacity
9. Safety

HEATING ELEMENTS

Elements used to create a high number of zones, and the two best choices for ovens.

- Quartz tube: These elements have a quartz tube surface. Due to brittleness, they are better suited for upper heating surfaces than on the bottom. They have a very quick response.

- Ceramic elements: Very good heating and longevity, less costly then quartz tubes.

ELEMENTS USED ONLY FOR LARGE ZONES

Commercial type metal-sheathed rods containing a coiled wire (CalRod™ by GE). Very good to use in bottom ovens where you don't need a lot of zones. Lower cost then Quartz and Ceramic and simplifies control system.

PROVIDING HEATING, AT LOW COST BUT WITH SOME DRAWBACKS

Bare coiled nickel/chrome wire. Life expectancy is not great and can lead to higher energy cost.

Gas flame or catalytic panels can have low energy costs, but they are hard to use in zones and can be affected greatly by drafts.

CLAMP FRAME

Moving clamp frames, stationary molds are the most popular in the Spa and Bath manufacturing industry. Some thermoforming manufacturers do not provide this option and instead require stationary clamps with a platen that moves the mold into the material.

CLAMP

Clamp frames need to be robust enough to withstand the amount of force encountered when the sheet meets the mold. The clamp pistons hold the sheet in the clamp frame so good vacuum lock is obtained.

UPPER PLATEN

An upper platen is desirable to automate plug assist. A plug assist can be used instead of screening to thicken up critical areas.

IR SENSOR

An IR Sensor can confirm when the sheet is at the right temperature and control the heat cycle time. All thermoformers should come with IR sensors.

VACUUM

The vacuum volume space should be at least 4x the volume of your largest mold. A vacuum gauge should be placed in a location easily visible to the operator. Before vacuum begins, the vacuum gauge should read at least 25" Hg. During the vacuum stage, the vacuum should not drop below 15" Hg.

MOLDS USED FOR SPAS AND BATHS

The most common molds used in the Spa and Bath markets are polyester molds. These are constructed of fiber reinforced polyester with a tooling polyester resin surface. The most common colors for tooling gel coats are red, orange, and black gel coats backed by FRP (fiber reinforced polyester).

Less common are aluminum molds. With the variety of models, aluminum molds make sense for high volume models. The benefit of aluminum molds is that they can be temperature controlled by running heating/cooling channels.

Products that have a large top rim should use a 4˚ to 7° draft angle to the mold. In the interior, 6" – 8˚ degrees should be used.

To prevent the cooled acrylic sheet from sticking in the mold, undercuts should be avoided. With the complexity of certain models, some undercuts can be achieved by using mold inserts. These mold inserts come out with the formed piece when separating from the mold and then are removed from the sheet by hand.

Some complex designs with large undercuts can be achieved by using two part molds. The mold separates from the formed sheet prior to part removal.

REMOVING THE THERMOFORMED SHEET FROM THE MOLD

The finished acrylic part can be removed safely from the mold at a temperature of 150°F to 170°F. The actual temperature is dependent upon the part geometry and mold complexity. If the formed acrylic is allowed to cool too much, the acrylic can grab on to the top rail and make it harder to be removed from the mold. This happens due to the shrinkage of the acrylic as it cools (a thermal expansion/contraction property). So it's important to demold when the temperature is between 150˚ to 170°F.

Although many thermoforming machines have air eject, this should only be used to break the vacuum lock. Too much air eject and you can end up with a broken piece.

BACKING

Acrylic is typically backed by FRP. In spas this is done in 2 layers. The first layer contains vinyl ester and chopped glass. After that sets, it's followed by another layer of FRP that is mineral filled and uses general purpose polyester. For spas, the first layer should always use vinyl ester instead of general-purpose polyester. Vinyl ester is more water resistant and does not result in blistering the acrylic. General purpose polyester as a first coat in Spas has resulted in blistering. This is not the case for bath tubs that intermittently have water in them.

The backing used for XTRA, which has ABS on the bottom, is polyurethane which doesn't have the emissions issues of FRP backing.

TROUBLE SHOOTING GUIDE

AFTER THERMOFORMING

PROBLEM	CAUSE	PREVENTION
COLOR VARIATION	Part pulled thin and backing color is showing through	Use screening to thicken up the part in the problem area. Use a colorant in the backing material
EXCESSIVE THINNING IN AREAS	Sheet is too thin	Use thicker sheet
	Sheet is too hot in thinning area	Use lower zone temperature or screening
BLISTERS	Excessive heat	Reduce heat. Use thermolabels to check the thermoforming temperatures Reduce heat cycle time Monitor bottom sheet temperature using an IR thermometer
	High moisture content in sheet	Use lower temperature. Keep acrylic covered with foil packaging
	Hot spot in oven	Fix elements. Use Thermoimager to discover any heat element issues
	Heat Cycle Time too long	Use higher heat settings and reduce heat cycle time
BUMP ON SURFACE	Dirt in mold	Use vacuum and tack cloth to clean mold
	Water droplets on sheet	Make sure sheet is dry prior to thermoforming
	Contamination	Contamination in sheet, replace if severe
BLUE OR COLOR SPOT ON SURFACE	Blue jean fiber on sheet prior to thermoforming	Have a "No Jean Policy"
		Use tack cloth to clean sheet before thermoforming.
ORANGE PEEL IN THINNER AREA	Sheet was heated too hot or had excessive moisture	Reduce heat in the areas where the part pulls thinner or implement screening

AFTER BACKING:

PROBLEM	CAUSE	PREVENTION
BLISTERS AFTER BACKING	Backing	Excessive gas generated by backing Improper backing chemistry Exposure of empty unit to high temperatures or direct sunlight may cause the backing to post cure and generate gas Storing units outside in the sun with heat trapping packaging
WRINKLES IN ACRYLIC SURFACE AFTER BACKING	Backing exotherm after application	Excessive backing temperature -- peak exotherm temperature should be kept below 180˚F.
	Uncured polyester	The polyester backing should cure in a hour or less where it's hard to the touch.

AFTER SPA IS FINISHED:

PROBLEM	CAUSE	PREVENTION
CRAZE	Stress + Solvent	Craze is caused by the exposure to stress and solvents
	In the manufacturing facility	Minimize stress in the sheet by following good thermoforming practices: Warm mold and acrylic up to temperature Do not wipe down the acrylic surface prior to glassing with acetone or IPA
	At shows, dealers	Do not wipe down the acrylic with IPA or rubbing alcohol. Use soap and water.
	At end user	Use mild soap and water to clean the acrylic surface. Use of acrylic safe cleaner
	Prolong UV exposure	Keep spa covered with insulating cover when not in use.
CRACKS	During shipment and cold weather	Make sure packaging protects against strap damage.
	At time of installation	Do not let the unit drop in place.
	Unlevel installation	Make sure pad remains level. Make sure the spa is well supported in the seats and along the rim.
	Fatigue: Thermal expansion/contraction	Keep spa covered with insulating cover when not in use.
	Poor FRP adhesion to the acrylic	Consult with resin supplier
BLEACHING OF THE SURFACE	TriChlor	Do not use TriChlor in spas. See PLASKOLITE bulletin.
	Excessive Oxidizer	Oxidizers should be used per manufacturer's instructions
	Other incompatible chemicals	Chemicals such as wintergreen oil (methyl salicylate) is not compatible with acrylic. Ointments, essential oils and aromatherapy fragrances may damage the acrylic surface.
	Prolong UV exposure	Keep spa covered with insulating cover when not in use.

PLASKOLITE

NORTH AMERICA'S LEADING MANUFACTURER OF THERMOPLASTIC SHEET

FOUNDED IN 1950

Our Mission: to deliver superior thermoplastic sheet, coatings and polymers to the world, through long-lasting customer relationships and hands-on customer service.

MANUFACTURING LOCATIONS

From our founding, PLASKOLITE strives to treat our employees, our customers, our community and the world, with kindness, dignity and respect. This drives our continuing effort to create sustainable products, in a sustainable manner, for future generations. This on-going commitment is expressed in the

PLASKOLITE Sustainable Ecosystem:

QUICK FACTS

STATUS: Privately held

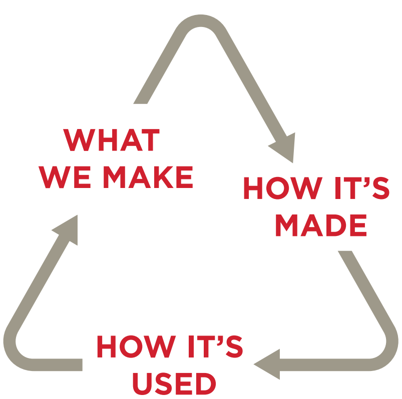
GLOBAL HEADQUARTERS: Columbus, OH

EMPLOYEES: 1900 Worldwide

MARKETS SERVED: Signage, Lighting, Retail Display, Construction, Transportation, Security, Bath & Spa, Industrial, Architecture, Green Houses

OUR PILLARS OF SUSTAINABILITY

EACH CONTRIBUTES TO MAKING THE WORLD A BETTER PLACE



WHAT WE MAKE	Versatile, high-quality, durable thermoplastic materials...not single-use plastics
HOW IT'S MADE	How we make our products reflects our overall philosophy of continuous environmental improvement
HOW IT'S USED	Our thermoplastics play an important role in advancing human well-being, energy conservation and quality of life

These suggestions and data are based on information we believe to be reliable. They are offered in good faith, but without guarantee, as conditions and methods of use are beyond our control. We recommend that the prospective user determines the suitability of our materials and suggestions before adopting them on a commercial scale.

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